Biomass, Carbon and Nitrogen Dynamics as Affected by Different Pruning Regimes in *Albizia procera* based Agrisilviculture System

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By

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To,

The Vice Chancellor,

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Subject: Submission of Ph.D thesis.

Sir,

I am forwarding herewith the thesis entitled "Biomass, carbon and nitrogen dynamics as affected by different pruning regimes in *Albizia procera* based agrisilviculture system" for the degree of Doctor of Philosophy in Agroforestry, Bundelkhand University, Jhansi. The work has been carried out at National Research Centre for Agroforestry, Jhansi under the supervision of Dr. Ram Newaj, Senior Scientist.

Thanking you.

Yours faithfully,

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Certificate

It is certified that this thesis entitled "Biomass, carbon and nitrogen dynamics as affected by different pruning regimes in *Albizia procera* based agrisilviculture system" is an original piece of work done by Mr. Shabir Ahmad Dar under my supervision and guidance for the degree of Doctor of Philosophy in Agroforestry, Bundelkhand University, Jhansi (India).

I further certify that:

- It embodies the original work of candidate himself.
- It is upto the required standard both in respect of its contents and literary presentation for being referred to the examiners.
- The candidate has worked under me for the required period at National Research Centre for Agroforestry, Jhansi.
- The candidate has put in the required attendance in the department during the period.

(Ram Newaj)
Supervisor

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Shabir

(Shabir Ahmad Dar)

Dedicated to my parents

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Introduction

1. INTRODUCTION

Agrisilviculture system is an agroforestry system for the concurrent of agricultural crops (including woody perennial crops) and forest crops. The forest crops serve in either a productive or a service role. Obviously each tree has a production function, at least on the day it is finally felled. Growing of trees on the farmlands, alone or in association with crops, provide food, fodder, fuelwood and timber besides environmental benefits by taking carbon out of the atmosphere and putting it back in the soil and in the biomass.

The development of agrisilviculture would increase both food and timber production on the same piece of land, while providing greater employment opportunities and a larger income to the peasant farmer. There are ample evidences to show that the overall productivity of an agroforestry system is generally greater than that of an annual system although not necessarily greater than that of a forestry or grassland system. The basis for the potentially higher productivity could be due to the capture of more growth resources e.g., light or water or due to improved soil fertility. Competition, which is a negative effect in this context, is usually a significant factor in simultaneous agroforestry system, even when there is evidence of increased combined productivity by both components (Ralhan *et al.,* 1992; Sharma and Singh, 1992; Jagdish Chander, 1998).

Trees having sparse canopy, fast growth, clean bole, nitrogen fixing capacity and protein rich fodder are most suitable for agrisilviculture system. *Albizia procera* Benth. (safed siris), being a moderately fast growing and nitrogen fixing tree have an advantage to include in agrisilviculture system. It is native to south Asia, distributed in humid and sub-humid tropics of India, Pakistan, Bangladesh, Myanmar, Malaysia and some parts of China (Luna, 1996). The species is prized for its fodder rich in proteins and mineral nutrients. It also provides small timber, pulp and firewood and is harvested in 12–15 years. It is increasingly being used for afforestation / reforestation both in social forestry and in agroforestry programmes in different tracts of India (Jha, 1994; Luna, 1996).

Shoot pruning has become an essential management practice in agroforestry systems for reducing both above and belowground competition with associated crops (Fownes and Anderson, 1991; Sinclair *et al.,* 1998), supplying organic materials to the soil and providing mulch during the cropping season (Mafongoya *et al.,* 1998; Kadiata *et al.,* 1998). However, as the functional balance of the tree is altered through pruning, it reacts both morphologically and physiologically in response to the changes and consequently,

the growth and development of shoots and foliage may be altered (Singh and Thompson, 1995). Conceptual models of tree growth after pruning claim that the amount of available carbohydrate will strongly influence the regrowth of trees (Erdmann *et al.*, 1993; Nygren *et al.*, 1996; Berninger *et al.*, 2000). However, if sufficient recovery time is provided after pruning, such a reduction in regrowth gradually decreases to zero (Uotila and Mustonen, 1994) and pruned trees may resume their normal growth status (Farnsworth and Niklas, 1995).

In tree-crop system canopy pruning alleviate shading of crops and appeared as an effective mean of increasing the light permeability (Dauzat and Eroy, 1997; Upadhyaya and Nema, 2003). Pruning also reduces the competitive ability of the trees, which allow the crop to take advantage of the higher nutrient availability under the alley cropping system (Haggar and Beer, 1993). Biomass yields and productivity of crops have also been reported higher under pruned trees (Osman *et al.*, 1998; Bayala *et al.*, 2002; Droppelmann and Brliner, 2003).

Carbon is considered one of the key pollutants contributing to global warming. The carbon cycle of terrestrial ecosystems plays a key role in regulating CO_2 concentration in the atmosphere (Moore and Braswell, 1994; Dixon *et al.*, 1994; Houghton *et al.*, 2000). Thus, enhancing carbon storage in terrestrial ecosystems will be a key factor in the maintenance of the atmosphere's carbon balance. Several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create C sinks (Winjum *et al.*, 1992; Dixon *et al.*, 1993; Krankina and Dixon, 1994; Dixon, 1995). Promoting agroforestry is one option many perceive as a major opportunity to deal with problems related to land-use and CO_2-induced global warming. Agroforestry has been recognized to be of special importance as a carbon sequestration strategy because of its application in agricultural lands as well as in reforestation programmes (Cairns and Meganck, 1994; Ruark *et al.*, 2003).

Claims on C sequestration potential of agroforestry systems are based on the same premise as for tree plantation: the tree components in agroforestry systems can be significant sinks of atmospheric C due to their fast growth and high productivity. By including trees in agricultural production systems, agroforestry can, arguably, increase the amount of carbon stored in lands devoted to agriculture, while still allowing for the growing of food crops (Kursten, 2000). The International Panel on Climatic Change

Review of literature

2. REVIEW OF LITERATURE

Management of the tree component in agroforestry systems at suitable age intervals is of vital importance to optimize the biomass production of understorey vegetation. Shoot pruning has become a necessary management practice in agroforestry for reducing both above and belowground competition with associated crops (Fownes and Anderson, 1991; Sinclair *et al.,* 1998). In agrisilviculture system, lower branches are removed from the tree upto certain height to facilitate penetration of light to understorey crops. However, frequent pruning can lead to decreasing production and slow death of trees (Dugma *et al.,* 1988; Romero *et al.,* 1993). The role of pruning on growth and biomass of trees, their consequence effects on biomass production of herbaceous layer and carbon buildup in soil is briefly reviewed in this chapter under following heads:

2.1 Pruning and tree growth

2.2 Pruning and biomass of trees

2.3 Pruning and growth/biomass of herbaceous layer (crops and weeds)

2.4 Carbon and nitrogen accumulation in trees and herbaceous layer

2.5 Nutrient dynamics in agroforestry systems

2.6 Trees and soil carbon

2.1 Pruning and tree growth

In agroforestry systems, trees and crops compete inevitably for light, nutrients and other resources. Pruning of the tree component is a powerful approach to regulate this competition (Frank and Eduardo, 2003). In agrisilviculture system, pruning facilitates penetration of light and alleviates shading of understorey crop and simultaneously increases the merchantable value of the tree component. Pruning of trees has been extensively used in silvicultural management to improve timber quality and provide easy access into the stand for inspection (Shepherd, 1961; Evans, 1992). It has been hypothesized that pruning will change stem shape to a more cylindrical form (Shepherd, 1986; Muhairwe, 1994). Larson (1965) found that in tamarack (*Larix laricina* (du Roi) K. Koch) reducing crown size by pruning resulted in proportionately less growth in the lower stem and a more cylindrical stem shape.

Impacts of pruning on the tree growth and development have been extensively studied in field experiments and it is clear that the impact of pruning on tree growth and

development depends not only on the amount of branches and leaves removed but also on the tree size, growth habits, pruning seasons and intensity and pruning frequency (Moller, 1960; Shepherd, 1961; Sprugel *et al.*, 1991; Kozlowski *et al.*, 1991; Uotila and Mustonen, 1994; Eamus, 1999; Porter and Hayashida-Oliver, 2000).

Pruning severity is the amount of live crown removed and it influences the growth response of the trees. It has generally been found that the impact of pruning on growth increases with the severity of pruning (Luckhoff, 1967; Fujimori and Waseda, 1972; Sutton and Crowe, 1975; Takeuchi and Hatiya, 1977; Karani, 1978; Dakin, 1982). It is clear from many studies that the minimum level of pruning that affects growth varies between species and this level needs to be identified before appropriate pruning prescriptions can be developed. For example, growth of *Pinus patula* Schl. and Cham. was reduced by removal of more than 25% of the lower green crown length (Karani, 1978). Sugi (*Cryptomeria japonica* Don.) was found to withstand slightly higher levels of pruning by removing 30% of lower green crown (Dakin, 1982) and in *Acacia mangium* Wild., growth was only affected if pruning removed more than 40% of lower green crown length (Majid and Paudyal, 1992).

Montigny and Smith (2001) used a range of residual crown lengths viz. 1.5, 2.5, 3.5, and 4.5 m for pruning severity plus no pruning (control) in 12 and 13 years old coastal western hemlock (*Tsuga heterophylla*) plantations. The results revealed that after 4 years, there were obvious downward trends in both average diameter and height with increasing pruning severity. Significant growth reduction appeared below a threshold of about 50% retained crown ratio. The most severe pruning treatment (1.5 m) reduced 4-year average diameter by 4.3 cm and height by 1.5 m, compared with the control.

Pinkard (2002) reported that removal of 80% leaf area in *Eucalyptus nitens* changed the growth trajectory such that long-term growth was likely to be reduced. In another study, Pinkard *et al.* (2004) reported that removal of crown length between 30 and 50% was appropriate for *E. globulus* plantations verging on canopy closure. The significant reduction in height growth associated with removal of 50 or 70% of crown length suggested that pruning should remain below 50% of crown length, if reduced stem growth of pruned trees was to be avoided. Stem volume was only significantly reduced over the period of the experiment by 70% pruning, but it was estimated that standing volume following removal of 50% of crown length would be reduced by 82 m^3 ha^{-1} over a 20–year rotation if there were no other silvicultural interventions. Several researchers

have found that tree growth may be significantly affected by pruning intensities higher than 35% crown pruning (Moller, 1960; Shepherd, 1961; Pinkard and Beedle, 1998). Zeng (2001) based on own and experimental results of others concluded that, for long-term pruning practice on an annual basis, an optimal pruning intensity for a young tree should be 20% at most.

Evidences from different studies suggest that the level of pruning that can be sustained at a given stand density without affecting growth is related to the growth rate of the species, and the timing, frequency and severity of pruning. For example, the removal of 40 – 50% of lower green crown length in *E. grandis* depressed both height and diameter increment (Plumptree, 1979; Bredenkamp *et al.,* 1980). Similarly, removal of more than 25 and 30% of the crown length of *Pinus patula* and *Cryptomeria japonica,* respectively reduces both height and diameter (Fujimori and Waseda, 1972; Karani, 1978; Dakin, 1982).

Pires *et al.* (2002) studied on different intensities of live crown pruning (0, 12.5, 25, 50 and 75%) in *Euclyptus grandis.* The growth in dbh, height and volume were larger for the control, being inversely associated with tree pruning intensity. A reduction of 26.76, 28.09 and 45.16% in dbh, height and volume, respectively at the age of 92 months were observed under a pruning intensity of 75%. In a similar study, Pinkard and Beedle (1998) also reported that removal of 50% crown length had no impact on height or diameter increment but removal of 70% of the lower crown length resulted in significant decrease in both height and diameter increments in *Eucalyptus nitenss* than control (no pruning). Sun-ZhiHu *et al.* (2004) found that under different pruning intensities, dbh increment in 20-30 years old white birch (*Betula platyphylla*) was significant and a decrease of 8–10% was observed in high intensity pruning treatment (2/3 H) in comparison to low intensity.

Ram Newaj *et al.* (2007) reported that in *Albizia procera* based agrisilviculture system, trees which were allowed to grow naturally (unpruned) attained maximum height, dbh and crown diameter than trees pruned upto 70% plant height and the growth of pure trees (without crop) was significantly ($P \leq 0.05$) less than trees in the agrisilviculture system .

2.2 Pruning and biomass of trees.

The growth of a tree is powered by the supply of assimilates which are chiefly produced by leaves. Trees having larger leaf mass ratio (leaf mass/ total plant mass) can produce more assimilates per unit plant mass and invest proportionately more assimilates to

growth (Poorter, 1998). Trees are commonly pruned by removing leaves and branches from the lower part of tree crown, leaving the stem and roots untouched. Consequently, the leaf mass ratio of pruned trees is diminished. Due to decreased assimilate production, the growth of pruned tree is generally reduced (Moller, 1960; Pinkad and Beedle, 1998; Pinkard *et al.,* 1999; Bandara *et al.,* 1999).

Biomass production is directly correlated with pruning intensity and severely pruned trees tended to produce less biomass after pruning than lightly pruned trees. Zeng (2001) reported that biomass production of *Ficus microcarpa, F. virens* and *Cinnamomum camphora* trees decreased following pruning, and this reduction was correlated with pruning intensity. Similar results have also been reported by Lehtpere (1957) and Uotila and Mustonen (1994). Biomass production in N_2-fixing leguminous trees might be influenced by the frequency and height of pruning. In an alley cropping with maize and cowpea, Dugma *et al.* (1988) found a significant effect of pruning height on biomass production of *Leucaena leucocephala, Gliricidia sepium* and *Sesbania grandiflora.* In a N_2-fixing leguminous tree species (*Gliricidia sepium*), and two non-N_2 fixing leguminous tree species [*Senna siamea* (*Cassia siamea*) and *Senna spectabilis* (*Cassia spectabilis*)] grown in an alley cropping, Sanginga *et al.* (1994) observed that 46% decrease in biomass was due to pruning in young *Gliricidia sepium.*

Bandara *et al.* (1999) reported that in five-year-old *Pinus radiata* D. Don trees, growing at an agroforestry site with an understorey of lucerne (*Medicago sativa* L.) or with no-understorey and either pruned or unpruned, the total biomass increment over one year was highest for unpruned trees with no-understorey (81 kg dry mass per tree), compared with 34 kg for unpruned trees grown with lucerne. Pruning reduced the increment by 27% in the no-understorey and 16% in the lucerne treatments.

Langstrom and Hellquist (1991) reported that when Scot pine trees (about 25 years old) were deprived of 50–75% of their needle biomass by three different pruning regimes (unilateral pruning, pruning from below and pruning from above), after four growing seasons, pruned trees had a total volume growth loss during the study period in the range of 24–33% compared with the control. Pinkard *et al.* (1999) found that in 3-years-old *Eucalyptus nitens* (Deane and Maiden) plantations, removal of 0, 50 or 70% of the length of green crown, the total biomass production was reduced by 20% immediately followed by 50% pruning whereas 70% pruning treatment reduces biomass production by 77%.

Pruning of trees in agrisilviculture system, while reducing shade of the understorey crop, usually reduces biomass production. Frank and Eduardo (2003) reported that highest biomass production of *Erythrina lanceolate* under total and partial pruning regimes was measured in the unpruned control, followed by trees with 50% of the leaf pruned every three months, while total pruning every six months resulted in the lowest biomass production. Zeng (2003) evaluated the effects of pruning on above ground biomass partitioning of trees with four pruning intensities (0, 20, 50 and 70%) and found that pruning reduced the aboveground leaf fractions of trees instantaneously.

Miah *et al.* (1997) found that in an agroforestry system, when *Acacia mangium*, *A. auriculiformis* and *Gliricidia sepium* were grown alone and in association with upland rice (*Oryza sativa*) and mung beans (*Vigna radiata*) under pruned and unpruned conditions, *Acacia mangium* attained the highest height (7.6 m), diameter (12.1 cm), and stem dry biomass (17 141 kg ha^{-1}), while *A. auriculiformis* produced the highest leaf (12 465 kg ha^{-1}), branch (16 368 kg ha^{-1}) and total biomass (43 935 kg ha^{-1}). The total biomass in pruned trees was 27–39% lower than in unpruned trees after 2 years.

2.3 Pruning and growth /biomass of herbaceous layer

Light is the principal limiting factor for the growth of understorey vegetation as light penetration decreases with the increased standing density of trees (Acciaresi *et al.*, 1994). In agroforestry systems trees reduces the availability of light to the intercrops (Suresh and Rao, 1999; Tomar *et al.,* 2000; Basavaraju *et al.,* 2001; Reynolds *et al.,* 2007)) and solar radiation appeared to be the most important factor for the growth and yield of crops. Shukla and Hazra, (1994) emphasized that the forage yield of grasses was directly proportionate to the photosynthetic active radiation (PAR) falling through the tree canopy in silvopastoral system.

In a tree-crop system shoot pruning can alleviate shading of crops while providing biomass for mulch or green manure. Prasad and Prasad (1997) suggested that in an agroforestry system reduction in crop yield could be minimized by proper pruning and lopping and can be compensated by standing biomass of trees. Shading can be minimized by intensifying the hedgerow pruning regime, i.e., more frequent pruning and lower pruning height, but this also limits the capacity of hedgerows for biomass production and nutrient recycling (Kang, 1993). Many workers have reported the effect of height and intensity of pruning on the biomass production (Dijkman, 1950; Das and

Dalvi, 1981; Osman, 1981; Pathak *et al.*, 1981; Pathak and Patil, 1982). A study conducted by Duguma *et al.* (1988) showed that less frequent pruning and higher pruning height increased hedgerow biomass yields but at the same time reduced the companion crop yield. In an intercropping experiment of corn and mung bean under coconut stands pruning appeared as an effective mean of increasing the light permeability of coconut stands (Dauzat and Eroy, 1997).

Solanki and Ram Newaj (1996) reported that in a tree-crop system pruning of MPTS on annual basis reduced competition between the trees and crops and pruned biomass compensated the reduction of grain yield. Ralhan *et al.* (1992) reported that in an agrisilvicultural system, pruning after third year permitted some recovery in yield of intercrop. Similarly in another study, topping of subabul canopy at 1.50 m significantly increases yield of cluster bean and sesame grown as understorey crop (Thenua *et al.*, 1999). Pollarding of trees at a height of 1.5 m from the ground, could avoid the negative impact of trees and sustainable advantage can be derived from *Albizia lebbeck* based agrosilvicultural system (Joseph *et al.*, 1999). In 10-years-old *Hardwickia binata, Anogeissus pendula* and *A. latifolia* plantations under different pruning intensities (10, 25, 50 and 75 %) higher grain yield was recorded with 75% pruning treatment and pruning had a significant effect on the intercrop (blackgram) yield (Handa and Rai, 2001–2002). In a tree management practice (pruning upto 50 % of height and unpruned) pruning had positive effect on yield of intercrop and differed significantly (Munna Ram *et al.*, 2000–01). In a similar study, Osman *et al.* (1998) reported that crop plants grown with pruned trees attained higher dry matter and leaf area index than those with unpruned trees

Droppelmann *et al.* (2000) reported that pruning in *Acacia saligna* reduced total tree biomass yields by a quarter but the introduction of annual intercrops after the pruning of trees outweighed this loss. The yields of the intercrops in the pruned tree treatments were similar to their yields when grown as monocrops. The calculation of Land Equivalent Ratio (LER) showed over yielding for intercropped pruned systems. The high values for LER indicate that there is complementarity in resource use between the different species. Dry matter yield of greengram and cluster bean in 8-year-old plantation of *Holoptelea integrifolia* was higher under lopped trees than unlopped trees (Paroda and Muthana, 1979). In another study, different canopy management treatments in 5-year-old *Morus alba* trees significantly affected growth and yield potential of urd (*Phaseolus mungo*) and

pea (*Pisum sativum*), both on north as well as south of the tree trunk (Thakur and Singh, 2002).

Samsuzzaman *et al.* (2002) revealed that shoot pruning of trees thrice a year had the highest significant positive effect on the crop yield, where 71% radish (vegetable) yield was increased with *Acacia nilotica* and 50% rice and 55% radish yields were increased with *Albizia lebbek.* Shoot pruning of *Acacia* twice a year was found more efficient to enhance rice yield by 27%. Droppelmann and Berliner (2003) reported that in *Acacia saligna* based tree-crop system, biomass yields and productivity of *Sorghum bicolor* per unit of land were highest when trees were pruned and intercropped. Upadhyaya and Nema (2003) reported that in *Acacia*-based agrisilviculture system different pruning intensities (20, 40, 60 and 80%) improved light penetration and significantly increased the yield of wheat and paddy rice. The optimum yield of wheat (19.89 q ha^{-1}) was obtained under 40% canopy pruning whereas in case of rice, the maximum yield of 25.02 q ha^{-1} was observed under 40% pruning intensity.

Okun Omo *et al.* (2001) reported that pruning of *Albizia niopoides* in 4 m wide alleys significantly improved height, leaf number, leaf area, and stover and grain yields of maize (cv. Suwan-2-SR). However, maize yield from 4m and 3m wide alleys did not significantly vary with pruning of *A. niopoides.* Bayala *et al.* (2002) reported that crown pruning (total-pruning, half-pruning and no-pruning) of *Vitellaria paradoxa* (karite) and *Parkia biglobosa* (nere) in agroforestry systems had significant effect on millet production and the highest millet grain yield and total dry matter were produced under total-pruned trees (507+or-49 and 2033+or-236 kg ha^{-1} $year^{-1}$, respectively). Ram Newaj *et al.* (2005) reported that in *Albizia procera* based agrisilviculture system, the grain yield of intercrop (soybean) was almost similar to that of pure crop (without tree) during 1st year of tree plantation, but grain yield of intercrop was increased by 10.57 and 33.64% respectively during second and third years with 70% pruning over trees allowed to grow normally (unpruned). After four years, the yield was 132.50% higher in 70% pruning than trees allowed to grow normally (unpruned).

Viswanath *et al.* (1997) reported that in a *Sesbania sesban* based alley-cropped with maize and cowpeas (*Vigna unguiculata*) the biomass and nitrogen yield increased with increasing pruning height. Maize grain yield was not significantly affected by pruning height, and the grain yield of alley-cropped maize was not significantly different from maize grown without hedgerows. Cowpea seed yield was decreased by alley cropping,

and was lowest with the 1 m pruning height. In another study, Miah *et al.* (1997) found that when *Acacia mangium*, *A. auriculiformis* and *Gliricidia sepium* were grown in association with upland rice (*Oryza sativa*) and mung beans (*Vigna radiata*) under pruned and unpruned conditions, growth, yields and yield atrributes of both crops were significantly better in the pruned than unpruned plots, with yields in the pruned plots similar to those in sole crop plots (when actual ground area occupied was considered). Crop yield reductions in the unpruned plots were 61 and 78% respectively, for rice and mung beans. Pruning and weeding operations in alley cropping system with *Leucaena leucocephala* reduced the competition for growth resources and maize grain yield was little affected by the tree (Chamshama *et al.*, 1998). Effect of crown pruning also varies with species, reasonable yields of sorghum were obtained when *Prosopis juliflora* was pruned, but yields were still heavily depressed with *Acacia nilotica* after pruning (Jones and Sinclair, 1996).

2.4 Carbon and Nitrogen storage in trees and herbaceous layer

Trees are considered to be a terrestrial carbon sink (Houghton *et al.,* 1998) and can theoretically sequester carbon both in situ (biomass and soil) and ex-situ (products). In 10-year-old *Terminalia amazonia*, the average values of carbon for stem, branches and foliage were 0.48, 0.43, and 0.42, respectively and carbon storage by different tree components was 4.9 Mg ha^{-1} year^{-1} (Montero and Kanninen, 2002). The average carbon stored in roots of urban trees (Amelanchier, Malus, Pyrus, and Syringa trees) in Pennsylvania, USA, ranged from 0.3 to 1.0 kg for smaller trees, those having 3.8 to 6.4 cm dbh, more than 10.4 kg for trees having 14.0 cm to 19.7 cm dbh. Average total carbon stored by cultivars ranged from 1.7 to 3.6 kg for trees less than 6.4 cm dbh and 54.5 kg for trees larger than 14.0 cm (Johnson and Gerhold, 2003). In even-aged pure stands of maritime pine and radiata pine carbon sequestration in total aboveground tree biomass of radiata pine, at stand level in the whole rotation (thinning and clear-cutting at 30 years) ranged from 3.4 Mg ha^{-1} year^{-1} to 5.9 Mg ha^{-1} year^{-1} whereas mean annual carbon storage for maritime pine, ranged from 2.3 to 4.6 Mg ha^{-1} year^{-1} for the same rotation length (Murias *et al.*, 2006). After 11 years in a mixtures of *Eucalyptus globulus* and *Acacia mearnsii* the aboveground biomass was twice as high as *E. globulus* monocultures and total annual belowground carbon allocation ranged from 14.6 to 16.3 Mg C ha^{-1} year^{-1} (Forrester *et al.*, 2006).

In 20-year-old teak (*Tectona grandis*) plantations estimated carbon storage averaged 120 t ha^{-1} and litter, undergrowth and soil compartments contain 3.4, 2.6 and 225 t C ha^{-1}, respectively and the carbon storage in harvest-age teak plantations to be 351 t C ha^{-1} (Kraenzel *et al.,* 2003). In 6-year-old plantations of *Gmelina arborea,* stand carbon ranged from 24.12 to 31.12 Mg ha^{-1} at different sites. Among the tree components, the stem wood accounted for maximum C (56.25%) followed by branches (19.8%), roots (18.51%) and foliage (7.01%). Mean annual C accretion at 6 years age of plantation was highest and it was 0.35, 2.66, 0.965 and 0.87 Mg ha^{-1} for leaf, stem, branches and roots, respectively. Total nitrogen accumulation in 6-year-old stands at different sites ranged from 212.9 to 279.5 kg ha^{-1} with a mean annual storage of 238.43 kg ha^{-1}. At 6 years, *G. arborea* stands sequestered 31.37 Mg ha^{-1} carbon (Swamy *et al.,* 2003). In a 16-year-old slash pine (*Pinus elliottii*) plantation the spatial distribution sequence of carbon storage ranked as soil layer > vegetation stratum > litter floor. Total carbon storage ranged from 264.834 to 323.978 t hm^{-2} with an average value of 291.663 t hm^{-2} which increased with the different densities of the slash pine plantation. Carbon storage of the vegetation stratum ranged from 96.641 to 110.717 t hm^{-2}, which amounted for 35.40% of the total carbon storage. Carbon storage of the different components was in the order of trunk > root > branch > leaf, while the carbon storage ratio of the above and belowground biomass ranged from 7.185 to 7.922 and descended along with an increase in the density of the vegetation stratum. Carbon storage of the litter floor increased from 5.746 to 9.818 t hm^{-2} along with increasing densities, which represented 2.83% of the total carbon storage (Fang *et al.,* 2003).

Peichl and Arain, (2006) found that in an age-sequence (2, 15, 30, and 65-year-old) of four white pine (*Pinus strobus* L.) plantation stands aboveground tree biomass became the major ecosystem carbon pool with increasing age, reaching 0.5, 66, 92, and 176 t ha^{-1} in the 2, 15, 30, and 65-year-old stands, respectively. Tree root biomass increased from 0.1 to 10, 18, 38 t ha^{-1} in the 2, 15, 30, and 65-year-old stands, respectively, contributing considerably to the total ecosystem carbon in the three older stands. Forest floor carbon was 0.8, 7.5, 5.4, and 12.1 t C ha^{-1} in the 2, 15, 30, and 65-year-old stands, respectively. Aboveground ecosystem carbon increased with age from 3 to 40, 52, and 100 t C ha^{-1} in the 2, 15, 30, and 65-year-old stands, respectively, due to an increase in aboveground tree biomass. Belowground ecosystem carbon remained similar in the early decades after establishment with 37, 39, and 39 t C ha^{-1} in the 2, 15, and 30-year-old stands, but

increased to 56 t C ha^{-1} in the 65-year-old stand due to an increase in root biomass. Kang *et al.* (2006) reported that in a 13-year-old mixed planatation of *Pinus massoniana* and *Cunninghamia lanceolata* carbon content varied with tissues and tree species, but the total carbon content of *Pinus massoniana* was higher than *Cunninghamia lanceolata.* The average tissue carbon contents of *Pinus massoniana* were: wood (58.6%) > root (56.3%) > branch (51.2%) > bark (49.8%) > leaf (46.8%), while those of *Cunninghamia lanceolata* were: bark (52.2%) > leaf (51.8%) > wood (50.2%) > root (47.5%) > branch (46.7%). The carbon storage in the tree layer occupied 23.90% of the total ecosystem and 97.7% of the vegetation layer. *Pinus massoniana* accounted for 65.39% of the total carbon storage in the tree layer. Trunks had the highest carbon storage, accounting for 53.23% of the trees in *Pinus massoniana* and 55.57% in *Cunninghamia lanceolata,* respectively. Roots accounted for about 19.22% of the total tree carbon. The annual net productivity of sequestered carbon of the mixed plantation was 5.96 t hm^{-2} a^{-1}, which was equivalent to fixing CO_2 of 21.88 t hm^{-2} a^{-1}.

Management of trees in agro-ecosystems such as agroforestry, ethnoforests, and trees outside forests can promote long-term locking-up of carbon in carved wood and new sequestration through intensified tree growing (Pandey, 2002). Tree-based systems produce non-wood and wood products for both home use and market sale. Due to their high biomass, these systems simultaneously offer potential for carbon storage (Roshetko *et al.,* 2002) and they could sequester carbon both in soil and vegetation (Kaur *et al.,* 2002; Oelbermann *et al.,* 2004; Makumba *et al.,* 2007). Long rotation systems such as agroforests, homegardens and boundary plantings can sequester sizeable quantities of carbon in plant biomass and in long-lasting wood products (Albrecht and Kandji, 2003).

In two agroforestry systems of crops in rows and silvopastoral system, the carbon storage and fixation in *Gliricidia sepium* was 309 kg C ha^{-1} and 124 kg C ha^{-1} $year^{-1}$, respectively in the silvopastoral system. Whereas in the crops in rows of the *G. sepium* carbon storage was 653 kg C ha^{-1} and the fixation rate 327 kg C ha^{-1} $year^{-1}$ (Arias-Sanchez *et al.,* 2001). In a silvopastoral system consisted of about six-year-old tree species of *Acacia nilotica, Dalbergia sissoo* and *Prosopis juliflora* with two species of grasses, *Desmostachya bipinnata* and *Sporobolus marginatus,* the total carbon storage in the trees + grass systems was 1.18 to 18.55 t C ha^{-1} and carbon input in net primary production varied between 0.98 to 6.50 t C ha^{-1} $year^{-1}$. Carbon flux in net primary productivity increased significantly due to integration of *Prosopis* and *Dalbergia* with grasses. Compared to

'grass-only' systems, soil organic matter, biological productivity and carbon storage were greater in the silvopastoral systems. Of the total nitrogen uptake by the plants, 4 to 21% was retained in the perennial tree components (Kaur *et al.*, 2002). Homegardens with an average age of 13 years store 35.3 Mg C ha^{-1} in their above-ground biomass and depending on management options, the time-averaged above-ground C stocks of homegarden systems could vary from 30 to 123 Mg C ha^{-1} (Roshetko *et al.*, 2002). In a poplar-based intercropping system, the carbon storage by age 14 years reached 12 t hm^{-2}. The leaf litters from poplar will add 1.3 t hm^{-2} a^{-1} organic carbon to the soil. Carbon sink of tree-wheat intercropped system was 1.776 t hm^{-2} a^{-1} as compared to monocropped wheat farm, whereas the wheat farm was just 0.264 t hm^{-2} a^{-1} (Liang and Thevathasan, 2003).

Albrecht and Kandji (2003) reviewed that the carbon sequestration potential of agroforestry systems was estimated between 12 and 228 Mg ha^{-1} with a median value of 95 Mg ha^{-1}. Therefore, based on the earth's area that is suitable for the practice (585–1215×10^6 ha), 1.1–2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years. Oelbermann *et al.* (2004) also reviewed that the potential of agroforestry systems to sequester C in aboveground components was estimated to be 2.1×10^9 Mg C $year^{-1}$ in tropical and 1.9×10^9 Mg C $year^{-1}$ in temperate biomes. A 10-year-old system with *Erythrina poeppigiana* sequestered C at a rate of 0.4 Mg C ha^{-1} $year^{-1}$ in coarse roots and 0.3 Mg C ha^{-1} $year^{-1}$ in tree trunks. In semi-arid, sub-humid, humid, and temperate regions average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C ha^{-1}, respectively. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha^{-1} yr^{-1}(Montagnini and Nair, 2004).

In 19, 10 and 4-year-old *Erythrina poeppigiana* and *Gliricidia sepium* alley cropping systems, C input from *G. sepium* was significantly greater compared to *E. peoppigiana* in 19-year-old system, Tree roots of 10 and 4-year-old *E. poeppigiana* represented 16 and 28% of the total C allocation. Carbon input from maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) residues were not significantly different between alley crops and sole crops in the 19-year-old system per unit of cropped land. Carbon input from maize and bean residues were significantly greater in alley crops than the sole crops. The greatest input of organic material occurred in the 19-year-old alley crop followed by 10 and 4-year-old alley crops (Oelbermann *et al.*, 2006).

Misra *et al.* (1998) reported that in *Eucalyptus nitens* the concentration of N in roots was similar to that for leaves, but the concentration of P was higher in roots compared with leaves and other aboveground components of trees. Temporal variation of N and P concentrations in roots did not match with that for the aboveground components of trees. Leaves and coarse roots accumulated higher proportion of total N and P than other components. By 34 months, total accumulated N and P in trees was 290 and 31 kg ha^{-1}, respectively. In a very poor sandy savanna soil, 800–1000 kg N ha^{-1} were accumulated during 7 years in *Acacia* stands. Nitrogen fixation was higher in *Acacia auriculiformis* than in *Acacia mangium.* Nitrogen cycling through litter fall was high in *Acacia* stands, upto 170 kg ha^{-I} $year^{-1}$, and low in *Eucalyptus* and *Pinus* stands. However, in *Eucalyptus* stands, slow litter decay and reduced N release from decaying litter resulted in a relative accumulation of organic N in the forest floor (Reversat, 1996). In forests comprising the canopy overstorey layer with or without the evergreen understorey layer, forests contain between 1631 and 4825 kg ha^{-1} less in overall C content and 41–224 kg ha^{-1} less N content than if the evergreen understorey layer is included. Additional N uptake by evergreen understorey vegetation was estimated between 6 and 11 kg N ha^{-1} yr^{-1} at year 50 for the overstorey-with-understorey forest compared to the overstorey-only forest. Notably higher amounts of C and N were simulated as stored in the forest floor and soil pools when the understorey was included (Chastain *et al.,* 2006). In multi species riparian buffers, cool season grass buffers and adjacent crop fields in central Iowa, poplar had the greatest aboveground live biomass, N and C pools, while switch grass had the highest mean aboveground dead biomass, C and N pools. Over the two year sampling period live fine root biomass and root C and N in the riparian buffers were significantly greater than in crop fields. Growing season mean biomass, C and N pools were greater in the multi species buffer than in either of the crop fields or cool season grass buffers (Tufekcioglu *et al.*, 2003).

2.5 Nutrient dynamics in agroforestry systems

Trees are able to mobilize nutrients from the subsoil and then return these nutrients to the top soil making them available for an annual crop (Buresh and Tian, 1998), hence trees may reduce nutrient leaching and form a 'safety-net' under the root zone of the annual crop (van Noordwijk *et al.,* 1996). The integration of trees into farmlands has been suggested to combat soil nutrient depletion in tropical cropping system (Sanchez, 1995). Some evidences exist that trees are able to reduce nutrient leaching in comparison to sole

cropped annuals (Seyfried and Rao, 1991), or they can take up nutrients below the rooting depth of crops (Hartemink *et al.*, 1996).

Tree-based land-use systems could sequester carbon in soil and vegetation and improve nutrient cycling within the systems (Kaur *et al.*, 2002). Agroforestry systems can play an important role in reducing nutrient losses. Litter production and quantities of nutrients recycled in litter are greater on fertile than on infertile soils, however, management techniques for accelerating nutrient fluxes through pruning appear to hold promise for increasing plant productivity on the infertile soils. Litter decomposition and soil organic matter dynamics in agroforestry systems might most easily be manipulated by managing woody vegetation to produce organic residues of a certain quality and to regulate soil temperature and moisture (Szott *et al.*, 1991).

In 8 years old maize alley cropping treatments, with *Erythrina poeppigiana* and with *Gliricidia sepium*, maize biomass and maize N content, N release from mulch and residue decomposition, and N mineralization were all higher in the alley crop than the sole crop by 2.2, 2.8, 5.0 and 2.1-fold, respectively. Soil microbial N was not significantly different between treatments, but increased by 80% during the cropping season (Haggar *et al.*, 1993). In another study, it was also observed that in a *Prosopis cineraria* and *Cicer arietinum* (chickpea) tree-crop system nutrient levels (N, P and K), moisture content and organic carbon of soil were higher under the tree canopy when compared to the open area. It was concluded that *P. cineraria* has no adverse effect on the productivity of chickpea crop but on the contrary it improves the productivity due to the improvement in soil nutrient status and conservation of moisture (Puri *et al.*, 1994)

Agroforestry systems influence the dynamics of P through the conversion of part of the inorganic P into organic P. The effect was higher in deeper layers because the rate of cycling is higher for organic P than for inorganic P and for diester than for monoester, and because the P in deep layers is normally less available to crop plants. Agroforestry would maintain larger fractions of P available to agricultural crops, thereby reducing P losses to the unavailable pools (Cardoso *et al.*, 2003). In five clones (G3, G48, 65/27, D121 and S7C1) of *Populus deltoids* (six-year-old) grown under agrisilviculture system, total N ranged from 184.3 to 266.3 kg ha^{-1}, P from 16.8 to 31.1 kg ha^{-1} and K from 81.9 to 128.7 kg ha^{-1}. Total N and P were highest in clone 65/27, while K in clone G48. Nutrients were lowest in clone S7C1. In general, maximum nutrients (N, P and K) were allocated to aboveground components (leaves > stem > branches) than belowground

components. Available N, P and K in the soil improved significantly after six years of planting. It was higher in 0–20 cm and decreased with soil depth. At 0–20 cm soil depth, N increased from 14.9% to 24.1%, P from 17.2% to 23.3% and K from 3.1% to 5.1% under different clones (Swamy *et al.*, 2006).

Nair *et al.* (2007) reported that in three pastures: a treeless pasture of bahiagrass (*Paspalum notatum*); a pasture of bahiagrass under 20-year-old slash pine (*Pinus elliotti*) trees (silvopasture); and a pasture of native vegetation under pine trees (native silvopasture), phosphorus concentrations were higher in treeless pasture (mean: 9.11 mg kg^{-1} in the surface to 0.23 mg kg^{-1} at 1.0 m depth) compared to silvopastures (mean: 2.51 and 0.087 mg kg^{-1}, respectively), and ammonium–N and nitrate–N concentrations were higher in the surface horizon of treeless pasture. The more extensive rooting zones of the combined stand of tree + forage may have caused higher nutrient uptake from silvopastures than treeless system. Further, compared to treeless system, soils under silvopasture showed higher P storage capacity.

In *Pinus patula* trees (8 to 34 years of age) the highest concentrations of most nutrients were found in the leaves but the maximum nutrient pool was contained in the bole which accounted for about 58 to 85% of the total aerial contents of different elements. Among the nutrients, N concentration (2.2%) was the highest, followed by Ca, Mg, K, P and Na. Nutrient contents in the standing crop increased with stand age and were nearly 2102, 1911, 875, 478, 285 and 82 kg ha^{-1} Ca, N, Mg, K, P and Na, respectively in above-ground biomass of the 34-year-old stand. The annual uptake of N was highest but its accumulation in the standing stock was lower than that of Ca in the 34-year-old stand. The uptake and storage of Mg closely resembled those of K (Singh, 1982). In a similar study, Turner and Lambert (1983) reported that in a 27-year-old stand of flooded gum (*Eucalyptus grandis*), of the 453 t ha^{-1} of aboveground organic matter present, 394 t was in the tree, 42 t in the understorey and 28 t in the forest floor. The total N, P, Ca, Mg and K contents of the stand were 739, 44, 1254 and 658 kg ha^{-1}, respectively, and the understorey contained 35, 35, 16, 24 and 49% of the aboveground distribution of these nutrients, respectively. Although the developing rainforest understorey comprised a relatively small portion (9.3%) of the total aboveground biomass, it played a disproportionate role in nutrient accumulation and uptake, and had an annual net accumulation of 14, 55, 59, 30, 44 and 69% of the aboveground organic matter, nitrogen,

phosphorus, calcium, magnesium and potassium, respectively. The net annual removal from the soil was 30, 1, 38, 5 and 31 kg ha^{-1} $year^{-1}$ for N, P, Ca, Mg and K, respectively.

In an age series (7, 17, 30, 46 and 56 years) of Himalayan alder (*Alnus nepalensis* D. Don) plantations, concentrations of nutrients were in the order N > K > Ca > P in most of the tree components and in understorey vegetation. The relative contributions of standing state of nutrients in different tree components of mature plantations were in the order; bole > branch > below-ground part > twig and leaf > catkin. Sequential arrangement of nutrient storage in tree components was: N > K > Ca > P. Soil total N and available P increased with plantation age. Annual inputs of nutrients to the forest floor via litter fall were: 183 to 235, 4.9 to 7.0, 33.5 to 39.5 and 9.2 to 10.8 kg^{-1} for N, P, K and Ca, respectively. Total annual accretion of N through biological fixation ranged from 29 to 117 kg ha^{-1} in different plantations. Nutrient use efficiencies decreased with plantation age for all nutrients except for calcium (Sharma, 1993). The nutrient concentration in different layers of the vegetation in 5 to 8-year-old poplar (*Populus deltoides*) clone D_{121} plantations were in the order: tree > shrub > herb, whereas the standing state of nutrients were in the order: tree > herb > shrub. Soil, litter and vegetation, respectively, accounted for 80-89, 2-3 and 9-16% of the total nutrients in the system. Annual transfer of litter nutrient to the soil by vegetation was 113.7 to 137.6, 11.6 to 14.6 and 80.1 to 83.2 kg ha^{-1} $year^{-1}$ for N, P and K, respectively. The nutrient use efficiency in poplar plantations ranged from 159-175 for N, 1405-1569 for P and 295-332 for K (Lodhiyal *et al.*, 1995).

2.6 Trees and soil carbon

Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter and root residues into the soil. Agricultural lands could absorb large quantities of carbon if trees are reintroduced to these systems and judiciously managed together with crops and/or animals (Oelbermann *et al.,* 2004). Farage *et al.* (2007) observed that by using appropriate management, soils can be turned into carbon sinks and it would be possible to make alterations within the structure of the current farming systems to convert these soils from carbon sources to net sinks. Annual rates of carbon sequestration in the range 0.08–0.17 Mg ha^{-1} $year^{-1}$ averaged over the next 50 years could be obtained. The most effective practices were those that maximized the input of organic matter, particularly farmyard manure (upto 0.09 Mg ha^{-1} $year^{-1}$), maintaining trees (upto 0.15 Mg ha^{-1} $year^{-1}$) and adopting zero tillage (upto 0.04 Mg ha^{-1} $year^{-1}$). Afforestation

of agricultural soils and management of forest plantations can enhance SOC stock through C sequestration (Lal, 2005).

Long rotation systems such as agroforests, homegardens and boundary plantings can sequester sizeable quantities of C in plant biomass and in long-lasting wood products. Soil carbon sequestration constitutes another realistic option achievable in many agroforestry systems (Albrecht and Kandji, 2003). Agroforestry systems have the potential to sequester atmospheric carbon in trees and soil while maintaining sustainable productivity (Oelbermann *et al.,* 2004). The impact of agroforestry systems on soil fertility has also been shown by several workers in terms of higher organic matter content, total nitrogen, available phosphorus and potash in the top soil, and improved microbial activities in the system (Varghese *et al*., 1978; Bavappa *et al*., 1986; Liyanage, 1994; Dagar, 1995 a, b).

Under agroforestry systems involving *Populus deltoides* and *Eucalyptus hybrid* tree with intercrops of aromatic grasses *Cymbopogon martinii* and *C. flexuosus* on an average, dry litter production of *P. deltoides* was 5 kg tree^{-1} yr^{-1} whereas of *E. hybrid* was 1.5 kg tree^{-1} yr^{-1}. Under the canopies of these two trees soil organic carbon was enhanced by 33.3 to 83.3 per cent and available nitrogen by 38.1 to 68.9 per cent over control in 0–15 cm soil layer. There was significantly higher fertility buildup under *P. deltoides* than *E. hybrid* (Singh *et al*., 1989). Similar observations were also made by Pal *et al.* (1985) in *Pinus patula* and Venkateramanan *et al.* (1983) in Bluegum (*Eucalyptus globules*) and black Wattle (*Acacia mearnsii*) of Nilgiri after 12 years of recycling.

Under different management systems change in soil organic carbon and nutrient status were observed by Lal (1989). He found that over a period of six years (12 cropping seasons), the relative rates of decline in the status of nitrogen and organic carbon was much less under hedge-row-cropping of *Leucaena* and *Gliricidia* as compared to normal arable crops. In a comparison of the carbon cycle under natural vegetation (of both rain forests and moist savanna) and cereal crops, gains to soil humus were equal to losses, at 1.9 Mg ha^{-1} yr^{-1} in the forest environment and 1.2 Mg ha^{-1} yr^{-1} under savanna. The soil humus contents of 63.3 and 57.0 Mg ha^{-1} yr^{-1} carbon, respectively were equivalent, making a number of assumptions, to topsoil organic matter levels of 4.2 % under forest and 3.8 % under savanna. The net loss of soil carbon under continuous arable cropping amounted to 2.5 per cent of its initial value with crop residues removed and 1.2 per cent where they are retained. Under continuous cereal cropping, the soil was being degraded

at substantial rate (Young, 1989). An alley cropping system maintained soil organic carbon levels over four years while a mono-cropped control showed a decrease (Atta-Krah, 1990). Under *Cacao* and *Cacao/Erythrina* over a 10 year period soil carbon increased 10 t ha^{-1} and 22 t ha^{-1}, respectively (Fassbender *et al.*, 1991).

Mazzarino *et al.* (1993) observed that in four, 9 year old, cropping systems: two alley cropping systems, involving leguminous trees (*Erythrina poeppigiana* and *Gliricidia sepium*) and two cropping systems without trees, either fertilized or not with N, higher total C and N, microbial C and N, water soluble C and soil moisture were found in the alley cropping treatments than in the treatments without trees. Total C and N values were high (40–45 and 2.4–2.8 g kg^{-1}, respectively), but microbial biomass C and N values (without conversion factors) were relatively low (50–62 and 7–11 mg kg^{-1}, respectively) as compared to other tropical ecosystems.

Grasses and trees planted on the degraded lands have a potential of sequestering 1.9 Pg C in 7 years as against emission of 2.27 Pg during the same (Gupta and Rao, 1994). In a 5 year study, Gupta (1995) reported that soil organic carbon increased from the initial value of 4.4 to 9.5, 9.4, 8.8, 8.0 and 7.6 g kg^{-1} under *Dalbergia sissoo, Pongamia pinnata, Leucaena leucocephala, Acacia nilotica* and *Dalbergia latifolia*, respectively. Further, continuous silvi-pastoral system for 7 years resulted in 13–56 % increase in SOC contents over the open grass (C = 6.0 g kg^{-1}).

Kaur *et al.* (2000) reported that in an agrisilvicultural systems of *Acacia*, *Eucalyptus* and *Populus* along with rice–berseem and single species tree plantations, microbial biomass carbon was low in rice–berseem crops (96.14 μg g^{-1} soil) and increased in soils under tree plantations (109.12–143.40 μg g^{-1} soil) and agrisilvicultural systems (133.80–153.40 μg g^{-1} soil). Microbial biomass was higher by 42% (microbial C) and 13% (microbial N) in tree-based systems as compared to monocropping. Microbial biomass immobilized 2.32–2.57% of the soil carbon and 4.08–4.48% of the soil nitrogen in tree-based systems. Soil carbon increased by 11–52% due to integration of trees along with the crops for 6–7 years.

The C cycle under a spatial agroforestry system showed that the system as a whole (soil, soil organisms, tree, crop and environment) is stable (Dagar and Anand Swarup, 2003). In a 16-year continuously cropped agroforestry system soil organic carbon levels declined in all treatments. The decline was most pronounced in the no-tree control

treatments with continuous maize and cowpea cropping, where SOC levels dropped from the initial 15.4 to 7.3–8.0 Mg C ha^{-1} in the 0–12 cm topsoil in 16 years. In the two continuously cropped alley cropping systems, one with *Leucaena leucocephala* and one with *Senna siamea* trees, SOC levels dropped to 10.7–13.2 Mg C ha^{-1}. Compared to the no-tree control treatments, an annual application of an additional 8.5 Mg ha^{-1} (dry matter) of plant residues, mainly tree prunings, led to an extra 3.5 Mg C ha^{-1} (0.2% C) in the 0–12 cm top soil after 11 years, and 4.1 Mg C ha^{-1} after 16 years (Diels *et al.*, 2004).

In a woody plant invasion of grassland over the past 150 years, the rates of soil C and N stocks in older wooded areas increased by 100–500% relative to remnant grasslands probable due to higher rates of organic matter production in wooded areas, greater inherent biochemical resistance of woody litter to decomposition, and protection of organic matter by stabilization within soil macro- and microaggregates (Liao *et al.*, 2006). In a similar observation, Arya (2006) reported that in a silvipastoral system soil pH and percent organic carbon increased in the 0–25 cm soil layer after 3 years of tree growth.

Oelbermann and Voroney (2007) reported that in a 13-year-old hybrid poplar alley cropping system, soil organic carbon after 13 years of alley cropping was 19 mg C g^{-1} compared to 11 mg C g^{-1} upon initiation of agroforestry. Soil organic C and N were not evenly distributed throughout the plow layer. The largest C and N pool occurred in the top 20 cm, which is due to the accumulation of organic material in the upper horizons as a result of no-till cultivation. Similarly, Oelbermann *et al.* (2006) also found that in 19 and 10-year *Gliricidia sepium* and *Erythrina poeppigiana* alley cropping system with *Arachis pintoi* as a groundcover, the soil organic carbon and N pools were significantly higher in the 19-year-old alley crop compared to the sole crop, but not significantly different in the 10-year-old system. Soil C and N (%) showed a similar trend as that of the SOC and N pools in both 19 and 10-year-old systems.

Agroforestry was predicted to reduce soil erosion by upto 70%, N leaching by 20–30%, and increase C sequestration over 60 years by upto 140 t C ha^{-1} (Palma *et al.*, 2007). The amount of organic C recycled varied from 0.8 to 4.8 Mg C ha^{-1} in gliricidia–maize and from 0.4 to 1.0 Mg C ha^{-1} in sole-maize. In sole-maize, net decreases of soil carbon of 6 Mg C ha^{-1} and 7 Mg C ha^{-1} in the topsoil (0–20 cm) relative to the initial soil C were observed. After 10 years of continuous application of tree pruning material, C sequestered in the topsoil (0–20 cm) of gliricidia–maize was 1.6 times more than in sole-

maize. A total of 123–149 Mg C ha^{-1} were sequestered in the soil (0–200 cm depth), through root turnover and pruning application in the gliricidia-maize system. It was concluded that gliricidia–maize intercropping system could sequester more C in the soil than sole–maize (Makumba *et al.*, 2007). The highest SOC pool was measured under *Hieronyma alchorneoides* and *Vochysia guatemalensis*, i.e. 131.9 and 119.2 Mg C ha^{-1}, respectively, whereas in the pasture it was 115.6 Mg C ha^{-1}. The SOC pool has not changed significantly under the tree species evaluated 14 years after establishment (Jimenez *et al.*, 2007).

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Biomass, carbon and nitrogen dynamics as affected by different pruning regimes in *Albizia procera* based agrisilviculture system" was undertaken at the Research Farm of National Research Centre for Agroforestry, Jhansi (UP) India, during two consecutive years in 2005–06 and 2006–07. The details of the materials used, experimental procedures followed and techniques adopted are described in this chapter.

3.1 Experimental site and climate

The site of the experimental field is situated at 25^0 27^l North latitude and 78^0 35^l East longitude, 271 meters above mean sea level (amsl) in the semi-arid tract of the central Indian plateau. Average annual rainfall of the region is 806 mm; about 80 per cent of which occurs between June and September, with several intermittent dry spells. The mean monthly temperature is generally high, with high degree of variation between a maximum 39.8 ^{0}C in May and June and minimum temperature 5.8^{0}C in December and January. In summer, temperature occasionally reaches upto 48^{0}C. The mean monthly evaporation in the area is highest in April to June (9.4 – 15.2 mm) and it ranges from 1.9 – 6.0 mm during other months of the year. The meteorological data during experimental period is given in Appendix–1 and illustrated in Figure 1.

3.2 Soil Characteristics

The soil in the experimental field was *parwa* representing inter-mixed black and red soil group of Bundelkhand regions (UP) India, covered under the order of Alfisol. It is medium in texture, moisture retentive and workability, prone to crust formation following rains and open weather conditions. It fails to sustain plant growth whenever drought spell exceeds 2–3 weeks even under mild evaporation situation. The physical properties of the soil are given in Table 3.1.

3.3 Cropping history

The experimental field was used for tree-crop interaction study in agrisilvicultural system during Feb., 2000 to Jan., 2005 in which *Albizia procera* was included as the tree component, blackgram – mustard and soybean – wheat crop sequences were taken as intercrops.

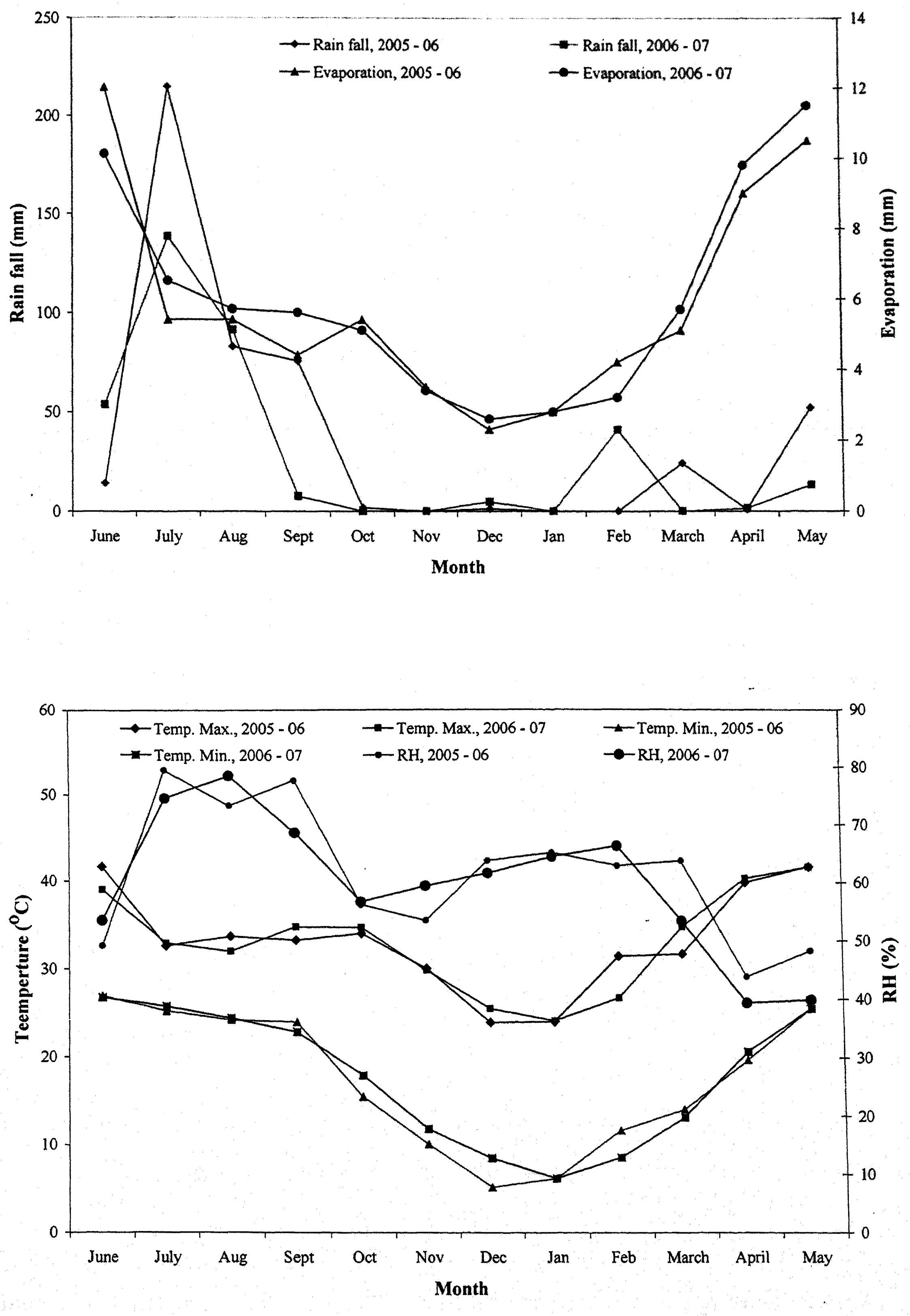


Figure 1. Mean monthly weather parameters during the study period

Table 3.1 Physical properties of the soil in the experimental field

Soil characteristics	Soil depth (cm)	
	0-15	15-30
1. Mechanical composition		
(a) Sand (%)	45.20	46.00
(b) Silt (%)	21.70	22.60
(c) Clay (%)	31.40	33.10
Texture class	Sandy clay loam	
2. Soil moisture characteristics		
(a) Field capacity (%)	25.30	25.70
(b) Permanent wilting point (%)	8.30	8.60
(c) Available soil moisture (mm m^{-1})	215.00	216.50
(d) Bulk density (g cm^{-3})	1.40	1.48

3.4 Experimental details

The experiment was conducted during 2005–2007 in a well established *Albizia procera* trees which were 5 years old, planted for tree-crop interaction study in 2000. The same experiment was used for present study with proper modifications as per technical programme of the experiment.

3.4.1 Treatments

1. Crop sequences:
   - Blackgram – mustard
   - Greengram – wheat
2. Pruning regimes:
   - 70% canopy pruning
   - 50% canopy pruning
   - Control (unpruned)

Pure tree (without crop)

Pure crop (without tree)

Spacing: 8 m x 4 m

Plot size: 5 76 m^2 (18 trees per plot)

Design: Split plot; main plot – crop sequence, and sub plot – pruning regimes

Replication: Three

Treatment combinations: 6 (Details of treatment combination are given in Table 3.2)

Pruning: Levels of canopy pruning were based on a percentage of green crown length. Pruning was done by pruning shears and lower branches were removed flush with the stem or parent branch. Pruning was done in October every year at least 15 days before sowing of rabi crop.

Table 3.2 Treatment combinations

Blackgram – mustard	Greengram – wheat
70% canopy pruning	70% canopy pruning
50% canopy pruning	50% canopy pruning
Control (unpruned)	Control (unpruned)

Layout of the experiment

Layout of the experimental field is given in Figure 2

3.4.2 Observations recorded

Tree growth

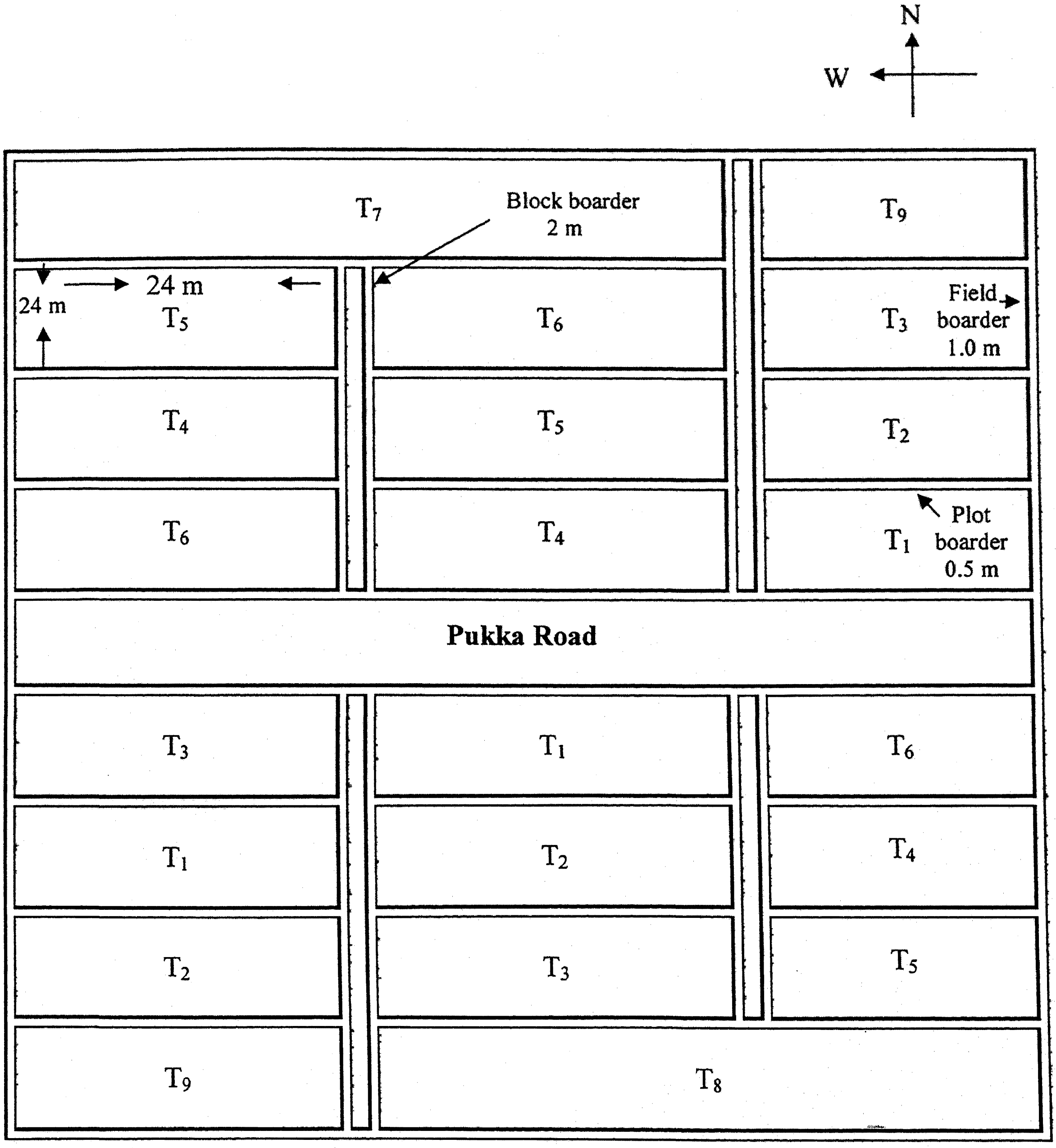
Growth parameters, diameter at breast height (dbh) and height were measured twice a year; first observation was taken in February and second in August. Diameter at breast height was measured at 1.37 m from ground on the main stem by tree caliper and total tree height by Ravi`s multimeter.

Pruned biomass

In 70 and 50% canopy pruning, pruned biomass (leaves and branches) of the individual trees was recorded and fresh samples of leaves and branches were taken for oven drying to estimate dry biomass. Pruned branches were taken out from the field for fuel wood and leaves were incorporated in the plot as green manure.

Biomass of tree

Destructive method was used to estimate above- and belowground biomass of trees by using an allometric equation. For destructive sampling, 12 trees from each pruning regime and crop sequence (36 trees from a crop sequence) and 6 trees from pure tree (without crop) were selected every year in order to represent the all dbh range within each treatment. The selected trees were harvested in October and/or November, 2005 and 2006 and dbh of each tree was recorded to regress the biomass of each component of the tree.



Main plot (crop sequence):	Blackgram – mustard	Greengram – wheat
Sub-plot (pruning regimes):	T_1 – 70% canopy pruning	T_4 –70% canopy pruning
	T_2 – 50% canopy pruning	T_5 – 50% canopy pruning
	T_3 – Control (unpruned)	T_6 – Control (unpruned)
	T_7 – Pure crop (Greengram – wheat crop sequence)	
	T_8 – Pure crop (Blackgram – mustard crop sequence)	
	T_9 – Pure tree (without crop)	

Figure 2. Layout of the experimental field

Aboveground tree biomass

The selected trees were cut close to the ground level with a manual saw and separated into the main bole, branches and foliage. Main bole and branches were cut into 1 m long logs. Fresh weight of these components was determined in the field immediately to avoid any weight loss with field scales. Component biomass was sub-sampled to evaluate the moisture content: we took 3 cm thick cross-sectional discs for each log and about 0.5 - 1.0 kg for foliage by level within the crown (bottom, middle and top). Aliquots were weighed before and after drying at 65°C to constant weight. The fresh to oven dry weight conversion factor was calculated for each tree. The dry weight of tree components (main bole, branch and foliage) was determined for each sample tree by using the conversion factor.

Belowground tree biomass

Measuring belowground biomass of large number of trees through excavation is not possible because excavation is tedious and very time consuming. It was decided to excavate only three trees from each pruning regime and crop sequence that represents the dbh range. Stumps (the tree part between the aboveground point where the stem was cut and the belowground points were the roots could be clearly individualized) were classified within the belowground component because they also include a large part of the root system.

Coarse root (>5 mm in diameter)

After tree felling, roots were excavated manually over a 4.5 m diameter area around each tree upto the maximum rooting depth. Each root was excavated until reaching the top end diameter of 0.5 mm. Roots were weighed in the field and sub-sampled to evaluate the moisture content. We took 2 to 5 cm thick cross-sectional discs for each root at 25 to 50 cm interval according to their thickness and length. After determining the fresh weight, these aliquots were dried at 65° C to constant weight to calculate the dry biomass.

Root: shoot ratio of the excavated trees was used as conversion factor (0.44 for 70% canopy pruning, 0.46 for 50% canopy pruning, 0.49 for control and 0.47 for pure tree) to calculate the root biomass of the harvested trees.

Fine (0 -2 mm) and small roots (2– 5 mm in diameter)

The fine and small root biomass was measured by monolith sampling method (MacDicken, 1997) in both cropping seasons (kharif and rabi). Five monoliths (size 0.25 m × 0.25 m ×0.60 m) were taken randomly from each pruning regime and crop sequence. Each monolith was divided in three pieces 0-15 cm, 15-30 cm and 30-60 cm, placed in a labeled plastic bucket and soaked overnight in water. Roots were gently washed over a series of sieves with mesh size of 2.0 and 0.5 mm, following the recommendations of Anderson and Ingram (1993). Roots were sorted into diameter classes of 0 - 2 mm (fine roots) and 2 – 5 mm (small roots). Roots from each of these categories were oven dried at 65 ^{0}C to constant weight and weighed.

Regression analysis and biomass estimation

Regression coefficients for biomass equations were estimated using the nonlinear model procedures of SYSTAT (Engelman, 2004). Allometric models of the form $Y = a(dbh)^b$, where Y is oven dry biomass (kg) and dbh is in centimeter, were used to develop the equations for the tree biomass components of the sampled trees. The equations were solved for all trees in each treatment, giving estimates of the individual tree biomass for the four tree components: main bole, branches, foliage and roots.

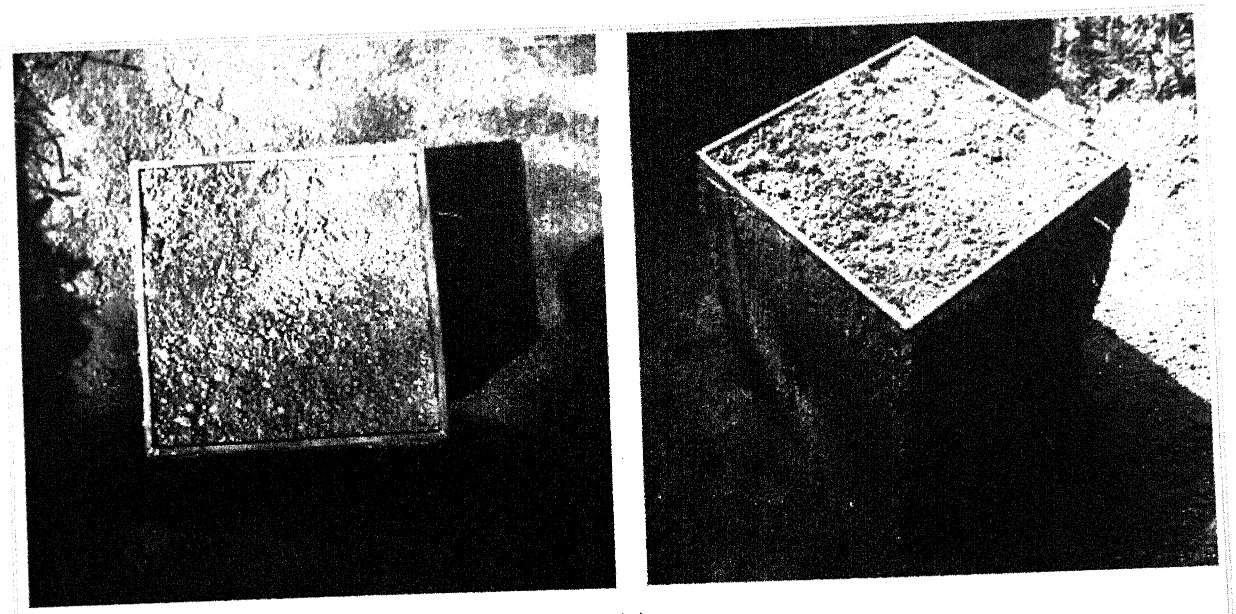
Regression equations were developed by clubbing the harvested trees of both the years (2005 and 2006) and used to estimate component biomass at different age viz., 5.0, 5.5, 6.0, 6.5 and 7.0 years in different treatment. Number of sampled trees, mean dbh and dbh range are given in Table 3.3.

Table 3.3 Mean dbh and dbh range of harvested trees used to develop allometric equation

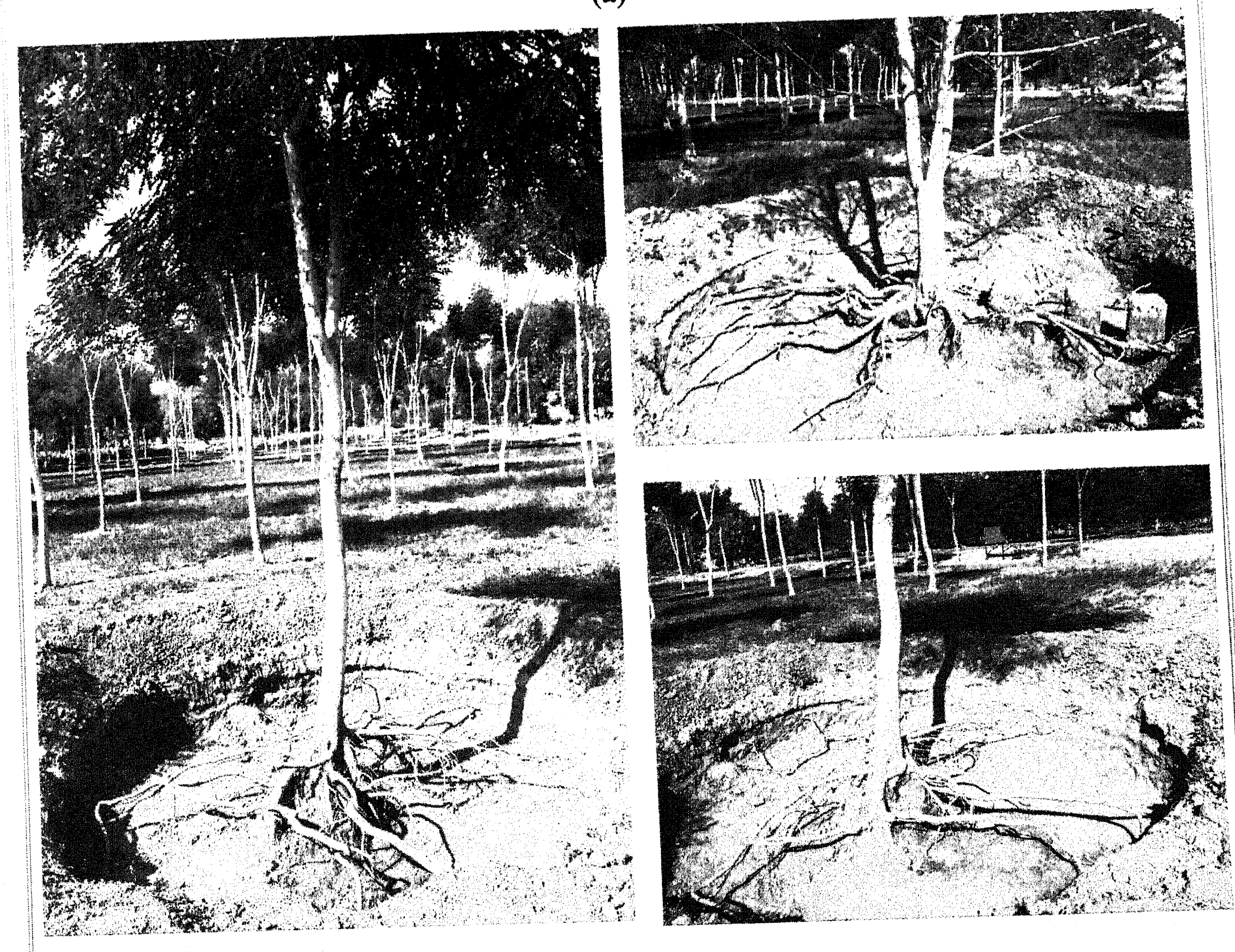
Treatment	No. of harvested trees	Mean dbh (cm)	Dbh range (cm)
70% canopy pruning	24	15.7	12.1 – 19.7
50% canopy pruning	24	16.4	10.1 – 26.7
Control (unpruned)	24	15.8	11.3 – 22.6
Pure tree (without crop	12	16.1	13.2 – 23.3

Litter fall

Litter fall was collected every month for two years (2005 – 06 and 2006 – 07) from February to January. Six litter traps (1.0 m x 1.0 m size) were placed randomly under the



(a)



(b)

Plate 1. (a) A view of monolith for estimating fine root biomass and (b) excavated trees for estimating root biomass

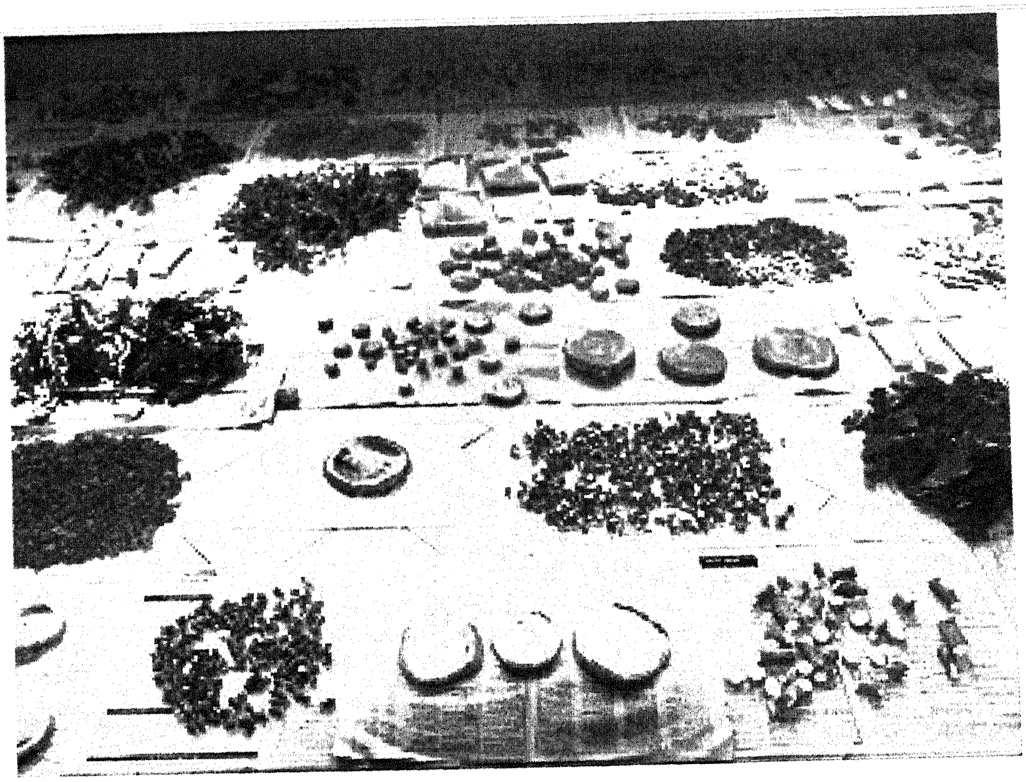


Plate 2. Samples of tree and herbaceous layer for estimating dry biomass

canopy of selected trees in each pruning regime and emptied monthly. Monthly litter fall values were summed to obtain total annual litter yield.

Intercrops

Blackgram (*Vigna mungo* Roxb.) – mustard (*Brassica juncia* L. Czern. & Coss.) and greengram (*Vigna radiate* Roxb.) – wheat (*Triticum aestivum* L. emend. Friori & Paol.) were grown as intercrops. The management practices of the individual crops have been given in Table 3.4.

Growth, yield and yield attributing characters of intercrops

Growth, yield and yield attributing characters were recorded at 0.5 m, 1.0 m, 2.0 m, 3.0 m and 4.0 m from tree base (the base of the center tree of each plot was considered for taking all the data related to growth, yield and yield attributing characters). The observations related to crop were taken left and right side of the tree base; finally the mean values of these observations were tabulated and analyzed as per design of the experiment. For determining crop yield per hectare, 220 m^2 net plot area was harvested and threshed separately.

Biomass of herbaceous layer

Aboveground biomass

Aboveground live biomass and floor litter of herbaceous layer was recorded monthly in each pruning regime and replicate. A quadrate (50 cm × 50 cm) was laid stratified on the ground at 0.5 m, 1.0 m, 2.0 m, 3.0 m and 4.0 m from tree base on both side of the tree, and vegetation (crop and weed) that originated inside the sampling frame was clipped and placed in the plastic bags for weighing. Floor litter on the soil surface was also collected in ~~each of~~ the sampling frame used for measuring herbaceous vegetation. These samples were washed with clean water to remove dust particles on the leaves. After air drying, the samples were dried in oven at 65°C to constant weight for dry biomass. Finally the mean values of these observations were tabulated and analyzed as per design of the experiment

Belowground biomass

Belowground biomass (root biomass) of herbaceous layer at 0–30 cm soil depth was also recorded every month during cropping period. A monolith (size 0.25 m × 0.25 m ×0.30 m) was taken from the same sampled area used for aboveground biomass and placed in a labeled plastic bucket and soaked overnight in water. Roots were gently washed over a

Plate 3. A view of intercropped mustard with *Albizia procera.* Tree with 70 and 50% canopy pruning can be seen in front and middle and unpruned in back side.

Plate 4. A view of intercropped wheat with *Albizia procera*

Table 3.4 Management practices used for growing intercrops during kharif and rabi season

Crop	Blackgram	Greengram	Wheat	Mustard
Variety	T-9	PDM – 54	HD – 2189	Varuna
Date of sowing	21^{st} July, 2005 17^{th} July, 2006	20^{th} July, 2005 17^{th} July, 2006	14^{th} November, 2005 16^{th} November, 2006	18^{th} November, 2005 23^{rd} November, 2006
Seed rate (kg ha^{-1})	14	14	100	5
Spacing Row to row Plant to plant	 30 cm 5 cm	 30 cm 5 cm	 25 cm 10 cm	 30 cm 10 cm
Fertilizer (kg ha^{-1}) Nitrogen Phosphorus Potassium Time of application	 20 40 00 Basal dressing	 20 40 00 Basal dressing	 40*,20**,20** 40* 40* *Basal dressing **CRI stage (after1^{st} irrigation) and late tillering stage (2^{nd} irrigation)	 30*,30** 40* 40* *Basal dressing **top-dressed (after 1^{st} irrigation)
Seed treatment	@ 1.5 g Thirum + 1.5 g Bavistin and 5 g rhizobium culture for 1 kg seed	@ 1.5 g Thirum + 1.5 g Bavistin and 5 g rhizobium culture for 1 kg seed	@3 g Thirum kg^{-1} seed	@3 g Thirum kg^{-1} seed
Pest and disease	@ 500 ml Monocrotophos 36% SL ha^{-1} sprayed within 15 and 20 days interval after sowing to control yellow mosaic virus	@ 500 ml Monocrotophos 36% SL ha^{-1} sprayed within 15 and 20 days interval after sowing to control yellow mosaic virus	–	Two spray of Phosphomidon @ 250 ml ha^{-1} at 15 days interval to control Aphids

Continue

Irrigations	–	–	4 irrigations (CRI, tillering, flowering and dough stages)	2 irrigations (1st at flowering and 2nd at siliquae formation)
Intercultural operations (manual thinning/weeding)	20 DAS	20 DAS	@ 1 kg 2, 4-D and 1 kg Isoproturan ha^{-1} at 20 -25 DAS to control *Chenopodium album* and *Phalaris minor*	20 DAS
Date of harvesting	1st October, 2005 8th October, 2006	5th October, 2005 2nd October, 2006,	2nd April, 2006 5th April, 2007	10th March, 2006 15th March, 2007

series of sieves with mesh size of 2.0 and 0.5 mm. All live and dead roots were sorted out and placed on soaking paper for few minutes to minimize the water content. The root samples were oven dried at 65 ^{0}C to constant weight and weighed.

Carbon analysis

The carbon content in all components was calculated from the samples taken for biomass determination. The oven dried samples (tree and herbaceous layer) were ground in a Wiley mill to pass through 1.0 mm mesh size sieves and analyzed for C by CHNS-O Elemental Analyzer (Euro EA 3000, Euro Vector SpA, Milan, Italy). Carbon content in each component was calculated by multiplying the carbon concentration in dry biomass of the respective component. The total carbon was estimated by summing the carbon content of each component.

Nutrient analysis

Oven-dried samples of both tree component and herbaceous layer were ground and sieved through 1.0 mm mesh size sieve. Nitrogen was determined by CHNS-O Elemental Analyzer. For analyzing P, K, Ca and Mg, 0.500 g of ground sample was digested in a di-acid mixture consisting of 4:1 HNO_3 : $HClO_4$ (Johnson and Ultrich, 1959) and then volume of digested material was made upto 100 ml with distilled water. P and K were determined by Spectrophotometer and Flame Photometer, respectively. Calcium and magnesium were analyzed by Atomic Absorption Spectrophotometer. Nutrient content in each component was calculated by multiplying the nutrient concentration in dry biomass of the respective component. The total nutrient was estimated by summing the nutrient content of each component

Soil analysis

Physico-chemical properties

Physico-chemical properties of the soil were determined at initial and final stage of the experiment. Three soil samples were taken from 0 – 15 and 15 – 30 cm soil depth in each pruning regime and crop sequence. Prior sampling, all vegetations were removed from the sampling area. Soil cores/slices were placed in plastic bag and core fragments were removed by using 5 mm screen. For making a sub-sample, all samples were screened in the plastic tub and mixed thoroughly. A sample from thoroughly mixed samples was used for analysis. Physico-chemical characteristics of the soil were measured by the methods as in Table 3.5.

Soil microbial analysis

For determination of soil microbial biomass carbon (MBC) and soil microbial biomass nitrogen (MBN), soil samples were taken randomly from each pruning regime and replicate at 0 – 15 cm soil depth before sowing of kharif crop and after harvesting of rabi crop during both the years. MBC and MBN were determined using the fumigation extraction methods (Vance *et al.*, 1987 for MBC and Brookes *et al.*, 1985 for MBN). Soil samples were conditioned by maintaining moisture to 40% water holding capacity. All results were expressed on an oven dry soil (105°C, 24 hr) basis.

Table 3.5 Methods for determining physico-chemical properties of the soil

Physico-chemical properties	Methods
Soil pH (1:2.5 soil : water ratio)	Combined Glass Electrode pH meter (Jackson,1958)
Electrical conductivity (d Sm^{-1} at 25 ^0C)	Solubridge Method (Richards,1954)
Organic carbon (%)	Walkley and Black's Rapid Titration Method (Jackson,1958)
Available nitrogen (kg ha^{-1})	Available $KMnO_4$ Method (Subbiah and Asija,1956)
Available phosphorus (kg ha^{-1})	Olsen's Method (Olsen *et al.*,1954)
Available potassium (kg ha^{-1})	Flame Photometer Method (Toth and Prince,1949)

3.4.3 Statistical analysis and interpretation of data

Analysis of variance was carried out to determine treatment and interaction effects. The variables were tested by using General Linear Model (GLM) of SYSTAT (SYSTAT 11). When treatment effect was found significant ($P \leq 0.05$), the Least Significant Difference (LSD) was calculated to compare treatment means.

Results

4. RESULTS

The data pertaining to biomass, carbon and nitrogen dynamics of trees and herbaceous layer as affected due to pruning of trees were recorded and statistically analyzed in order to test the level of significance. The results obtained during the study period are presented in this chapter with the help of tables and graphs at appropriate places.

4.1 Tree growth

The growth of *Albizia procera* (dbh and height) is shown in Table 4.1, which clearly indicates that dbh and tree height increased with tree age. The annual increment in dbh and height was 2.7 cm and 1.5 m, respectively which was stable at 5.0, 6.0 and 7.0 years of the age. The dbh of tree exhibited significant ($P \leq 0.05$) variation only at 5 years age due to crop sequence, whereas tree height exhibited significant variation throughout the study period. The dbh growth was slightly higher (13.32 to 18.65 cm) in blackgram – mustard than greengram – wheat crop sequence. Tree height was significantly ($P \leq 0.05$) higher in blackgram – mustard (7.33 to 10.65 m) than greengram – wheat crop sequence.

The canopy pruning significantly influenced the tree growth. Among pruning regimes, the trees in control (unpruned) had significantly ($P \leq 0.05$) higher dbh and height than 50 and 70% canopy pruning. The dbh varied from 14 to 19.07 cm, 13.40 to 18.55 cm and 12.48 to 17.81 cm in control (unpruned), 50 and 70% canopy pruning, respectively during the study period. Similarly, height of the tree was in the range of 7.77 to 10.90 m, 7.14 to 10.76 m and 6.76 to 10.01 m in control (unpruned), 50 and 70% canopy pruning, respectively. Growth of pure trees (without crop) was comparatively less than the trees in the agrisilviculture system and their dbh varied from 12.37 to 16.75 cm whereas tree height was in the range of 6.97 to 9.52 m.

4.2 Tree biomass

4.2.1 Pruned biomass

The annual pruned biomass obtained from 70 and 50% canopy pruning is given in Table 4.2. Pruned biomass was higher in greengram – wheat than blackgram – mustard crop sequence during 2005 but it was higher in blackgram – mustard crop sequence during 2006. In 70% canopy pruning, leaf and branch biomass was 29% and 32% higher than 50% canopy pruning, respectively

Table 4.1 Growth of *Albizia procera* at different age in agrisilviculture system

Crop sequence	DBH (cm)					Height (m)				
	5.0	5.5	6.0	6.5	7.0	5.0	5.5	6.0	6.5	7.0
Blackgram – mustard	13.32	14.59	16.08	17.34	18.65	7.33	8.12	8.96	9.98	10.65
Greengram – wheat	13.27	14.37	15.89	17.05	18.35	7.12	7.95	8.59	9.75	10.46
LSD (0.05)	0.01	NS	NS	NS	NS	0.08	0.12	0.11	0.16	0.06
Pruning regime										
70% canopy pruning	12.48	13.84	15.59	16.53	17.81	6.76	7.54	8.35	9.47	10.01
50% canopy pruning	13.40	14.46	15.86	17.10	18.55	7.14	7.98	8.76	9.85	10.76
Control (unpruned)	14.00	15.15	16.51	17.96	19.07	7.77	8.59	9.22	10.27	10.90
LSD (0.05)	0.16	0.26	0.47	0.32	0.38	0.33	0.24	0.18	0.36	0.21
Pure tree (without crop)	12.37	13.13	14.68	15.91	16.75	6.97	7.53	7.95	8.61	9.52

Table 4.2 Pruned biomass (t ha^{-1}) from 70 and 50% canopy pruning

Pruning regime	Component	2005		2006	
		Blackgram – mustard	Greengram – wheat	Blackgram – mustard	Greengram – wheat
70% canopy pruning	Leaf	0.80 (0.004)	0.99 (0.002)	1.12 (0.03)	1.05 (0.02)
	Branch	1.03 (0.01)	1.06 (0.003)	1.34 (0.07)	1.22 (0.04)
50% canopy pruning	Leaf	0.24 (0.004)	0.27 (0.003)	0.34 (0.02)	0.31 (0.03)
	Branch	0.30 (0.004)	0.37 (0.01)	0.44 (0.03)	0.40 (0.03)

4.2.2 Standing live biomass

Standing live biomass was predicted by using allometric equations, which express dry weights of individual tree components as a function of dbh, had high R^2 values and accounted for 0.97, 0.93, 0.95, 0.98 and 0.98 of the variance in 70% canopy pruning; 0.95, 0.96, 0.97, 0.98 and 0.98 of the variance in 50% canopy pruning; 0.95, 0.98, 0.96, 0.99 and 0.99 of the variance in control (unpruned) and 0.97, 0.98, 0.90, 0.99 and 0.99 of the variance in pure tree (without crop) for main bole, branch, foliage, root and total biomass, respectively (Fig. 3)

4.2.3 Tree biomass

Changes in biomass accumulation of *A. procera* over different age is shown in Table 4.3, which clearly indicates that standing biomass increased with the tree age but increment in biomass accumulation was almost stable at different age of the tree. Allocation of biomass in different tree components was in the order of branch > root > main bole > foliage. Of the total biomass, branch biomass accounted for 25–33%. Total biomass did not exhibit significant variation due to crop sequences, except at 5 years age. Total biomass of tree at 5 years age was 26.11 and 25.90 t ha^{-1} in blackgram – mustard and greengram – wheat crop sequence, respectively and the biomass accumulation at the age of 7 years was 51.75 and 50.32 t ha^{-1} in blackgram – mustard and greengram – wheat crop sequence, respectively.

Among pruning regimes, tree biomass was significantly ($P \leq 0.05$) higher in control (unpruned) than 50 and 70% canopy pruning. Mean annual increment in biomass accumulation was 4.84, 6.30, 7.63 t ha^{-1} $year^{-1}$ in 70% canopy pruning, 50% canopy pruning and control (unpruned), respectively. Biomass accumulation in various tree components was in the order of branch > root > main bole > foliage in control (unpruned) and 50% canopy pruning but in 70% canopy pruning the biomass accumulation in different tree components was in the order of main bole > root > branch > foliage. In control (unpruned), branch biomass represented about 40–41%, roots 33%, main bole 15–16% and foliage 11–12% of the total tree biomass at different age of the tree. In 50% canopy pruning, share of branch biomass was also maximum (31–33%) of the total tree biomass, followed by roots 31–32%, main bole 24–26% and foliage 11–12%. However in 70% canopy pruning, the contribution of main bole was maximum

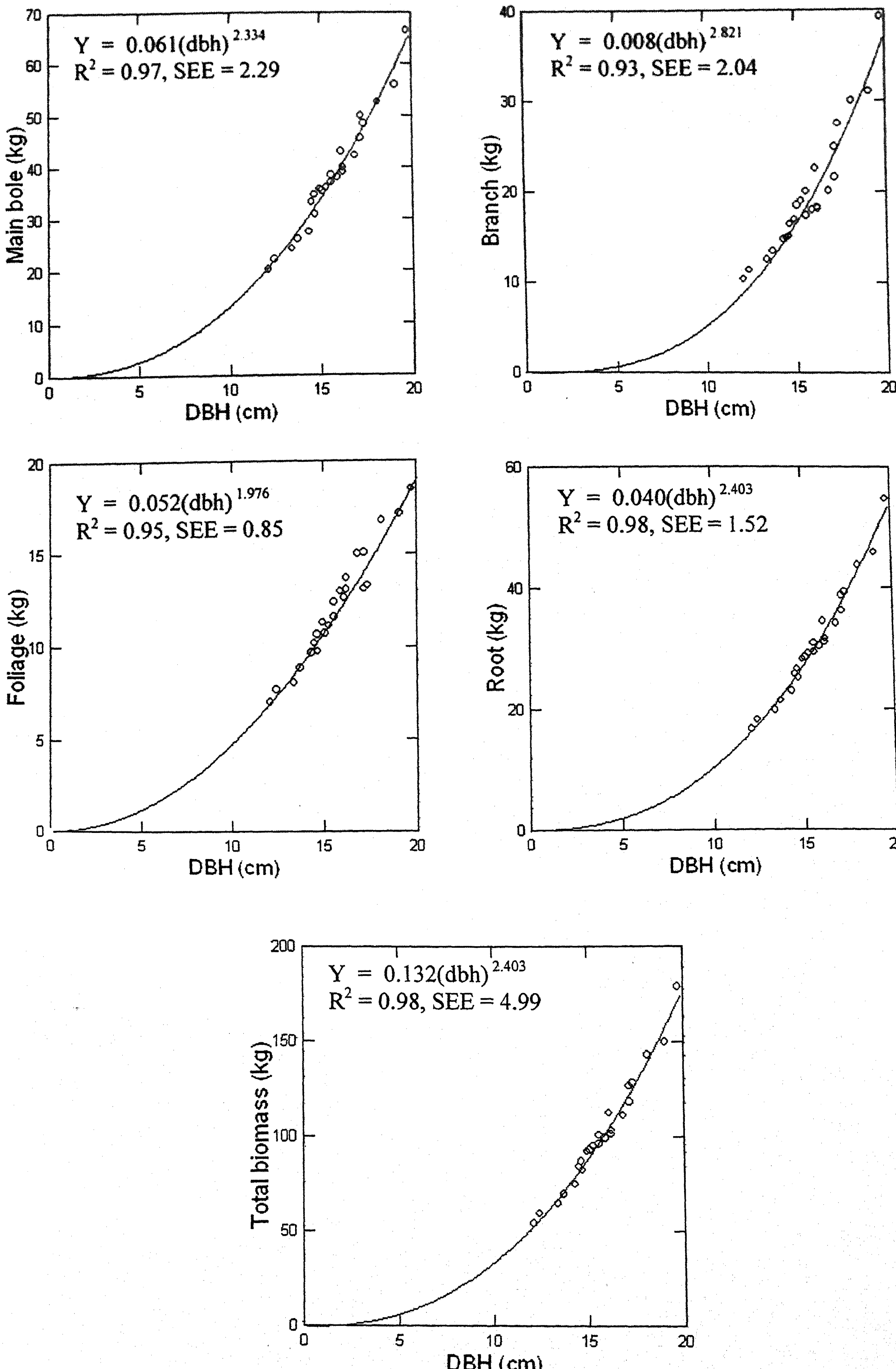


Figure 3 (a). Relationship between component biomass and dbh of 70% canopy pruned trees (No. of sampled trees = 24).

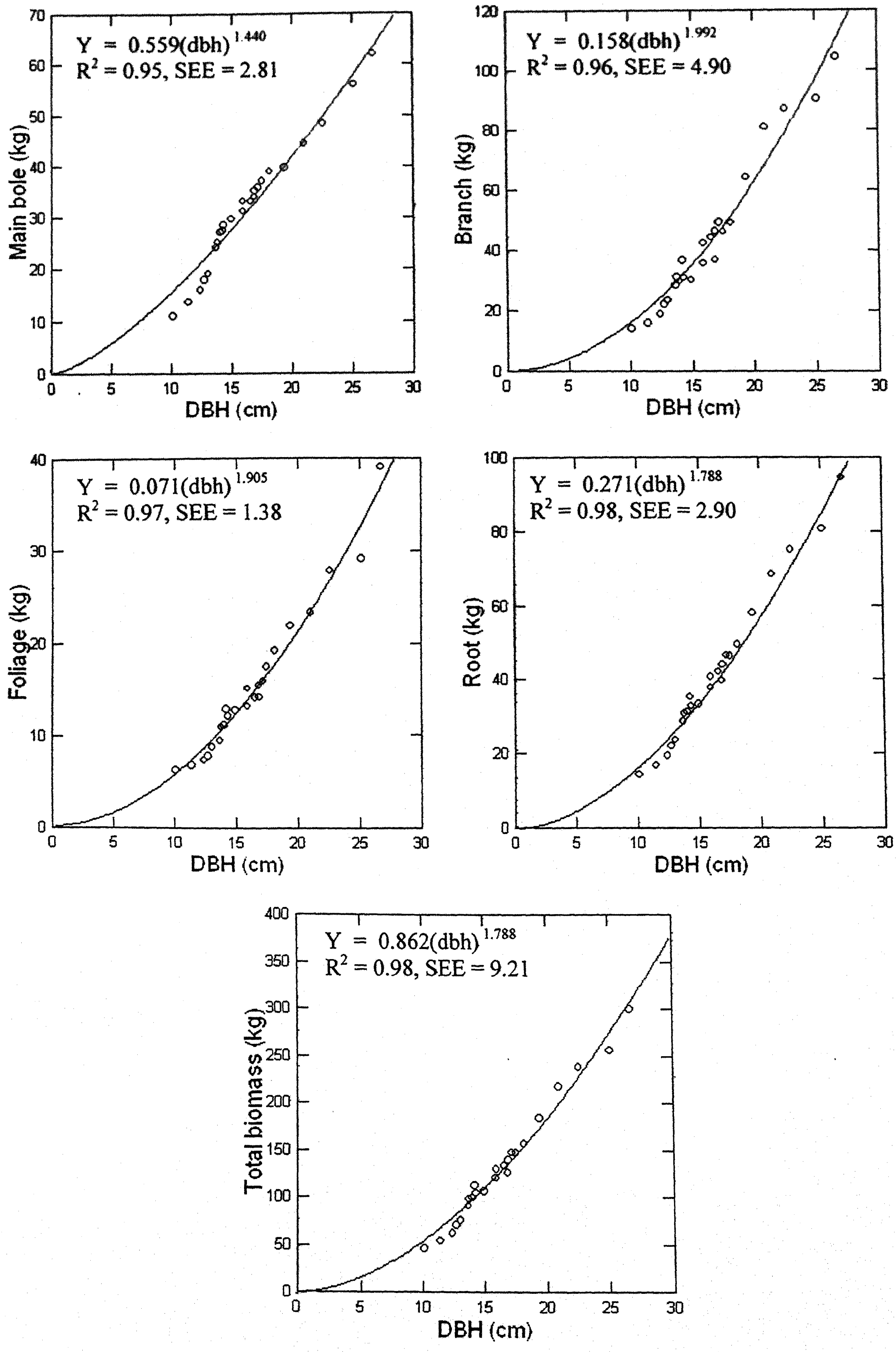


Figure 3 (b). Relationship between component biomass and dbh of 50% canopy pruned trees (No. of sampled trees = 24).

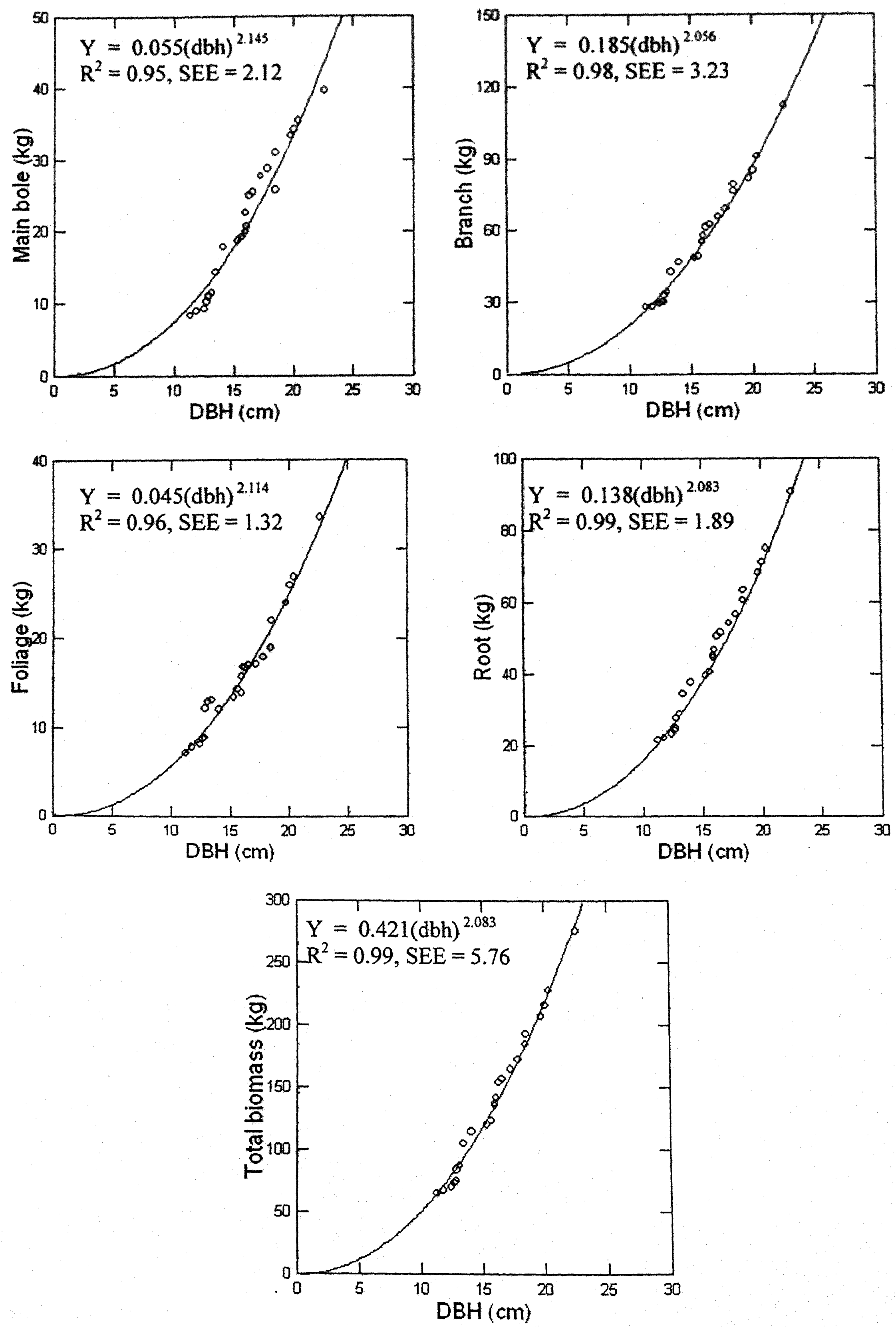


Figure 3 (c). Relationship between component biomass and dbh of control (unpruned trees). No. of sampled trees = 24

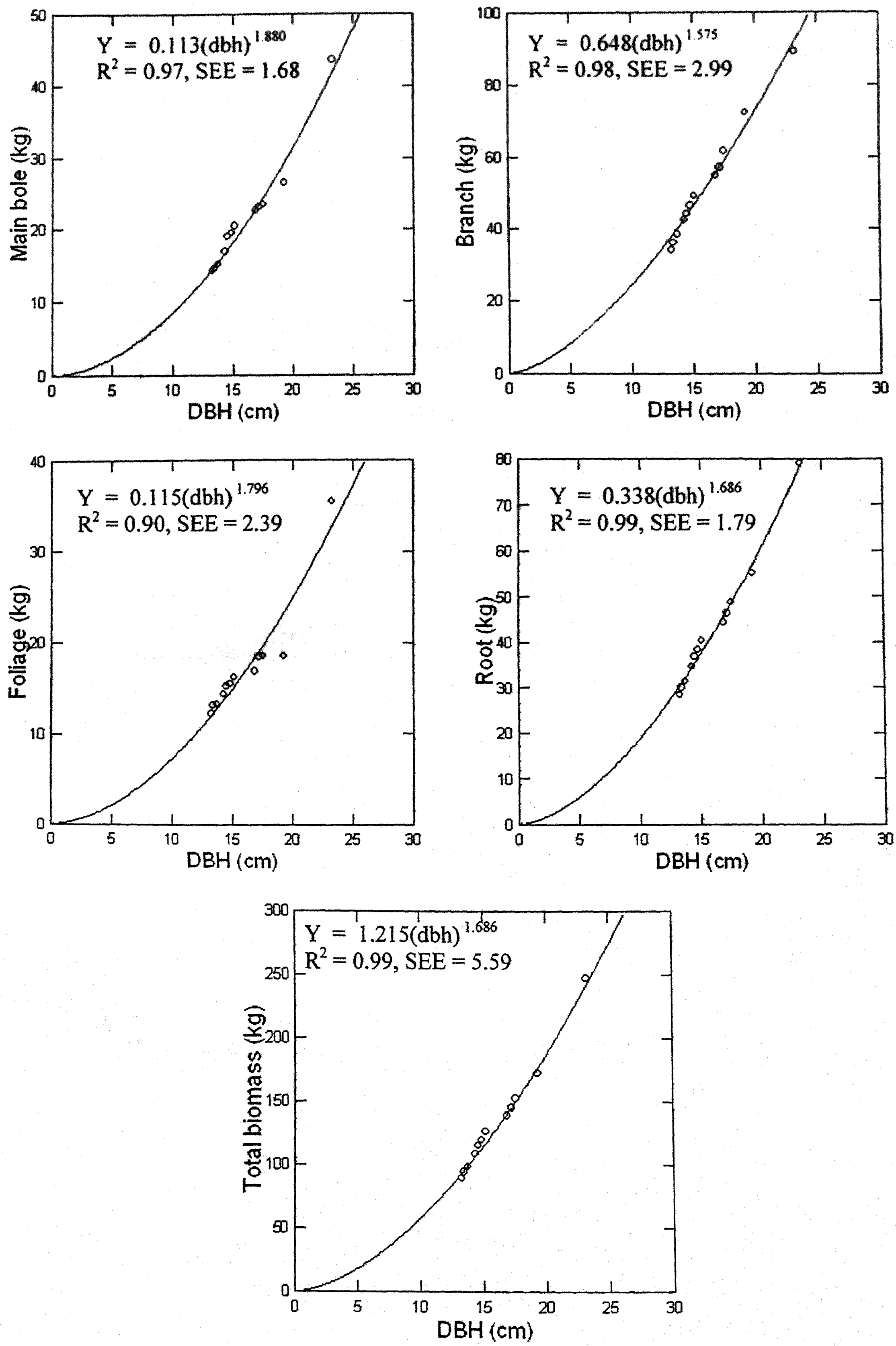


Figure 3 (d). Relationship between component biomass and dbh of pure tree (without crop). No. of sampled trees = 12

Table 4.3 Biomass (t ha^{-1}) of *A. procera* at different age in agrisilviculture system

Age (years)	Tree component	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% Canopy pruning	50% Canopy pruning	Control (unpruned)		
5.0	Foliage	3.08	3.06	0.02	2.38	3.11	3.72	0.07	3.28
	Branch	8.33	8.26	NS	3.09	8.67	13.12	0.20	10.62
	Main bole	6.41	6.36	NS	6.89	7.32	4.93	0.15	3.99
	Root	8.29	8.22	0.05	5.38	8.76	10.62	0.19	8.40
	Total	26.11	25.90	0.14	17.74	27.86	32.39	0.62	26.29
5.5	Foliage	3.68	3.59	NS	2.92	3.60	4.39	0.12	3.66
	Branch	10.02	9.75	NS	4.13	10.10	15.43	0.30	11.67
	Main bole	7.70	7.48	NS	8.76	8.17	5.84	0.31	4.46
	Root	9.95	9.68	NS	6.89	10.04	12.52	0.32	9.30
	Total	31.35	30.50	NS	22.70	31.91	38.18	1.03	29.09
6.0	Foliage	4.46	4.37	0.08	3.69	4.28	5.27	0.28	4.47
	Branch	12.21	12.00	0.09	5.79	12.10	18.42	0.85	13.91
	Main bole	9.43	9.19	NS	11.58	9.31	7.03	0.57	5.51
	Root	12.12	11.87	NS	9.18	11.81	14.99	0.78	11.23
	Total	38.22	37.43	NS	30.24	37.50	45.71	2.45	35.12
6.5	Foliage	5.20	5.06	NS	4.15	4.97	6.26	0.18	5.15
	Branch	14.46	14.07	0.34	6.85	14.17	21.78	0.51	15.76
	Main bole	10.89	10.52	NS	13.31	10.44	8.37	0.48	6.39
	Root	14.19	13.79	NS	10.59	13.61	17.77	0.52	12.83
	Total	44.74	43.44	NS	34.90	43.19	54.18	1.67	40.13
7.0	Foliage	5.99	5.83	NS	4.80	5.78	7.15	0.27	5.64
	Branch	16.84	16.33	NS	8.43	16.58	24.76	0.85	17.05
	Main bole	12.51	12.20	NS	15.80	11.70	9.57	0.52	7.02
	Root	16.41	15.96	NS	12.64	15.67	20.24	0.75	13.95
	Total	51.75	50.32	NS	41.67	49.73	61.72	2.34	43.66

(38–39%) of the total biomass, followed by roots 30%, branch 17–20% and foliage 12–13% at different age of the tree.

The biomass of pure tree (without crop) was 23–41% and 6–14% less than control (unpruned) and 50% canopy pruning in the agrisilviculture system, respectively but it gave 5–48% higher biomass than 70% canopy pruning in the same system. The change in biomass accumulation with age was almost similar to tree grown in the agrisilviculture system. The annual increment in biomass accumulation in pure tree was 5.25, 5.85 and 6.23 t ha^{-1} $year^{-1}$ at 5, 6 and 7 years age (Table 4.3).

4.3 Litter biomass

Litter production did not exhibit significant variation due to crop sequence during 2005 – 06 and was almost similar in both the crop sequences (Table 4.4). However, it was significantly ($P \leq 0.05$) higher in blackgram – mustard (1001.45 kg ha^{-1} $year^{-1}$) than greengram – wheat crop sequence during 2006 – 07. The influence of pruning is very much obvious from the data given in Table 4.4, which indicates that litter production was significantly ($P \leq 0.05$) highest in control (unpruned) followed by 50 and 70% canopy pruning. Litter production in control (unpruned) was 47 and 145% higher than 50 and 70% canopy pruning, respectively. Over all, the litter yield during May, June and July months was less; August, September and October months was moderate and during November, December, January, February and March months was highest during both the years (Fig. 4). In pure tree (without crop), litter production was comparatively 18% less than control (unpruned) in the agrisilviculture system.

(.)

Table 4.4 Litter fall production (kg ha^{-1} $year^{-1}$) of *A. procera* under different treatments in agrisilviculture system

Crop sequence	Year	
	2005 – 06	2006 – 07
Blackgram – mustard	882.23	1001.45
Greengram – wheat	882.10	975.40
LSD (0.05)	NS	14.08
Pruning regimes		
70% canopy pruning	511.96	586.54
50% canopy pruning	847.07	980.36
Control 9unpruned)	1287.47	1398.39
LSD (0.05)	5.86	10.26
Pure tree (without crop)	1091.69	1191.07

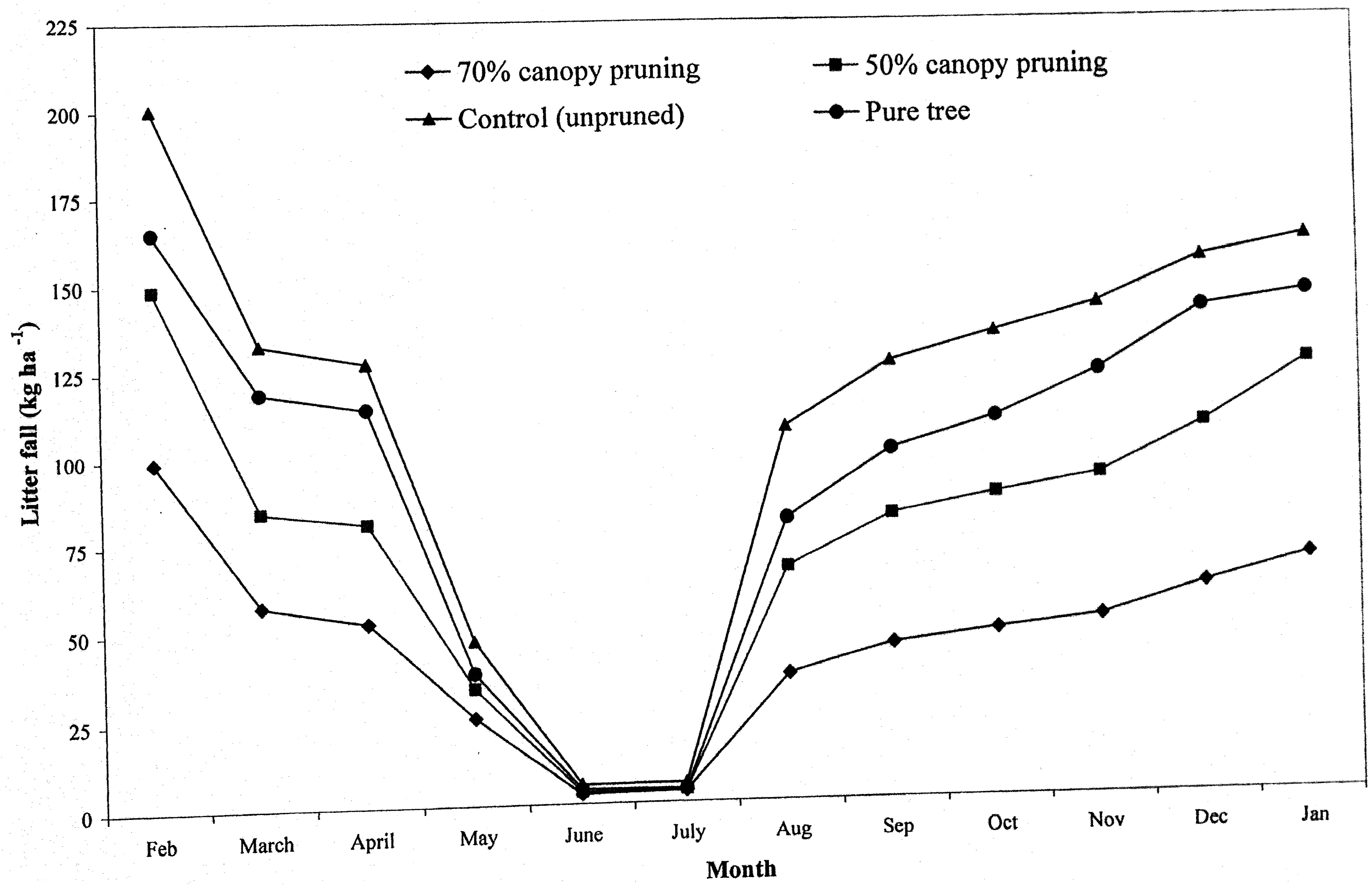


Figure 4. Monthly litter fall of *Albizia procera* (Mean monthly values of 2005 – 06 and 2006 – 07)

4.4 Fine and small root biomass

4.4.1 Fine root biomass

Fine root biomass of *A. procera* during cropping period is shown in Table 4.5. The maximum fine root biomass was observed during kharif cropping (rainy season) as compared to rabi cropping (winter season) and increased with tree age. Fine root concentration was highest in upper 0 – 15 cm soil layer and decreased with increasing the soil depth. Fine root biomass at 0 – 30 cm soil depth was about 81% of the total fine root biomass recorded at 0 – 60 cm soil depth in both kharif and rabi cropping.

Fine root biomass was significantly ($P \leq 0.05$) higher in blackgram – mustard than greengram – wheat crop sequence. During kharif cropping, fine root biomass was 523.77 and 719.53 kg ha^{-1} in blackgram – mustard whereas 505.66 and 705 kg ha^{-1} in greengram – wheat crop sequence in 2005 and 2006, respectively. Similarly, during rabi cropping, fine root biomass was 477.43 and 678.12 kg ha^{-1} in blackgram – mustard whereas 434.83 and 628.94 kg ha^{-1} in greengram – wheat crop sequence in 2005 – 06 and 2006 – 07, respectively.

Among different pruning regimes, control (unpruned) had significantly ($P \leq 0.05$) higher fine root biomass than 50 and 70% canopy pruning during both cropping periods. During kharif cropping, fine root biomass in control (unpruned) was 43 and 28% higher than 50 and 70% canopy pruning, respectively in both the years. During rabi cropping, fine root biomass was less as compared to kharif cropping but trend in biomass accumulation was similar to kharif cropping in different pruning regimes. The combined influence of crop sequence and pruning was significant ($P \leq 0.05$) on fine root biomass (Table 4.6). Fine root biomass of tree was significantly higher in blackgram – mustard crop sequence under different pruning regimes than greengram – wheat crop sequence in both the years. In pure tree (without crop), fine root biomass was 70–123% higher than trees grown in the agrisilviculture system.

4.4.2 Small root biomass

The biomass of small root was higher in kharif cropping than rabi cropping (Table 4.7). Small root biomass concentration was highest at 15 – 30 cm soil layer and this layer contributed 52% of the total small root biomass at 0 – 60 cm soil depth, whereas 0–15 cm soil layer contributed only 19–21% of the total small root biomass in both the years.

Table 4.5 Fine root biomass (kg ha^{-1}) of *A. procera* during cropping period at different soil depths

Cropping period	Soil depth (cm)	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
Kharif, 2005	0 – 15	261.09	255.36	0.20	229.71	247.31	297.66	3.51	484.39
	15 – 30	165.54	161.24	0.22	135.57	156.71	197.88	3.98	373.60
	30 – 60	97.14	89.06	0.28	61.17	71.40	146.73	3.73	234.77
	Total	523.77	505.66	0.58	426.45	475.42	642.27	6.77	1092.76
Kharif, 2006	0 – 15	335.47	329.20	0.42	303.63	319.05	374.32	5.34	592.72
	15 – 30	222.50	221.10	0.16	187.85	207.63	269.93	4.24	324.88
	30 – 60	161.56	154.70	0.45	139.29	149.60	185.50	3.50	292.39
	Total	719.53	705.00	1.03	630.77	676.28	829.75	9.61	1209.99
Rabi, 2005 – 06	0 – 15	240.06	226.82	1.29	200.03	229.56	270.73	3.73	454.85
	15 – 30	153.90	134.56	0.25	119.53	137.24	175.93	3.01	370.21
	30 – 60	83.47	73.45	0.38	48.21	67.09	120.08	4.05	191.42
	Total	477.43	434.83	1.47	367.77	433.89	566.74	5.52	1016.48
Rabi, 2006 – 07	0 – 15	328.47	302.86	0.19	280.66	303.89	362.85	3.63	578.71
	15 – 30	200.79	195.16	0.20	171.72	186.07	236.13	3.23	323.07
	30 – 60	148.86	130.92	0.39	123.06	131.71	164.90	4.11	289.91
	Total	678.12	628.94	0.56	575.44	621.67	763.88	5.94	1191.69

Table 4.6 Interaction effects of crop and pruning on fine root biomass (kg ha^{-1}) during cropping period

Treatment	Crop sequence							
	Blackgram – mustard				Greengram – wheat			
	0 – 15	15 – 30	30 – 60	Total	0 – 15	15 – 30	30 – 60	Total
	Kharif, 2005							
70% canopy pruning	236.71	138.03	67.68	442.42	222.71	133.10	54.65	410.46
50% canopy pruning	248.97	158.69	73.33	480.99	245.64	154.73	69.47	469.84
Control (unpruned)	297.59	199.88	150.40	647.87	297.73	195.88	143.07	636.68
LSD (0.05)	4.96	NS	NS	9.57				
	Kharif, 2006							
70% canopy pruning	300.01	186.18	140.89	627.08	307.26	189.51	137.69	634.46
50% canopy pruning	322.89	211.55	153.28	687.72	315.22	203.71	145.91	664.84
Control (unpruned)	383.51	269.78	190.51	843.80	365.13	270.08	180.48	815.69
LSD (0.05)	7.56	6.00	NS	13.60				
	Rabi, 2005 – 06							
70% canopy pruning	201.48	122.77	49.55	373.80	198.58	116.29	46.87	361.74
50% canopy pruning	239.64	146.06	67.80	453.50	219.49	128.43	66.37	414.29
Control (unpruned)	279.07	192.88	133.07	605.02	262.40	158.97	107.10	528.47
LSD (0.05)	5.28	4.26	5.72	7.81				
	Rabi, 2006 – 07							
70% canopy pruning	285.16	177.13	133.75	596.04	276.16	166.32	112.36	554.84
50% canopy pruning	312.83	184.85	141.51	639.19	294.95	187.29	121.91	604.15
Control (unpruned)	388.25	240.39	171.32	799.96	337.46	231.88	158.48	727.82
LSD (0.05)	5.14	4.57	NS	8.40				

Small root biomass was significantly ($P \leq 0.05$) higher in blackgram – mustard than greengram – wheat crop sequence. During kharif, small root biomass was 252.49 and 293.07 kg ha^{-1} in blackgram – mustard crop sequence and 237.19 and 283.26 kg ha^{-1} in greengram – wheat crop sequence in 2005 and 2006, respectively. Similarly, during rabi, small root biomass was 201.67 and 242.54 kg ha^{-1} in blackgram – mustard crop sequence whereas 196.91 and 236.53 kg ha^{-1} in greengram – wheat crop sequence in 2005 – 06 and 2006 – 07, respectively.

Small root biomass exhibited significant ($P \leq 0.05$) variation due to pruning and was highest in control (unpruned) followed by 50 and 70% canopy pruning. Small root biomass in control (unpruned) was 44–67% and 129–177% higher than 50 and 70% canopy pruning, respectively in kharif and rabi cropping during both the years. In pure tree (without crop), small root biomass was 78–129% higher than trees grown in the agrisilviculture system.

4.5 Biomass of herbaceous layer during kharif and rabi season

4.5.1 Kharif season

Biomass of herbaceous layer (crop and weed) increased with advancement of crop growth but rate of accumulation was higher after one month of sowing and increment in biomass accumulation after one month was more or less stable (Table 4.8). Among the crops, greengram accumulated significantly ($P \leq 0.05$) higher biomass as compared to blackgram. In greengram, monthly increment in crop biomass was 227 kg ha^{-1} whereas in blackgram the increment was 195 kg ha^{-1}. Similarly, monthly weed biomass in both the crops varied from 227.74 to 352.49 kg ha^{-1} and 167.42 to 298.88 kg ha^{-1} in blackgram and greengram, respectively during both the years. Floor litter and root biomass was also higher in greengram than blackgram. Root biomass (0 – 30 cm soil depth) in greengram varied from 49.09 to 85.43 kg ha^{-1} and 40.78 to 90.77 kg ha^{-1} during different months of growing period whereas in blackgram it varied from 42.93 to 69.86 kg ha^{-1} and 39.76 to 69.14 kg ha^{-1} in 2005 and 2006, respectively. Grain yield of blackgram was significantly higher than greengram in both the years.

Among different pruning regimes, 70% canopy pruning accumulated significantly ($P \leq 0.05$) higher herbaceous biomass than 50% canopy pruning and control (unpruned). The crop, weed, floor litter and root biomass was about 2.4, 2.0, 2.7 and 2.0 times higher, respectively in 70% canopy pruning than control (unpruned) during both the years. The

Table4.7 Small root biomass (kg ha^{-1}) of *A. procera* during cropping period at different soil depths

Cropping season	Soil depth (cm)	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
Kharif, 2005	0 – 15	53.81	48.82	0.54	24.73	44.46	84.74	3.74	107.95
	15 – 30	130.16	124.16	0.48	85.58	116.29	179.61	2.75	270.74
	30 – 60	68.52	64.21	0.44	37.19	65.16	96.74	3.71	138.43
	Total	252.49	237.19	0.48	147.50	225.91	361.09	6.51	517.12
Kharif, 2006	0 – 15	68.12	65.58	0.55	35.28	62.04	103.23	5.93	127.19
	15 – 30	141.11	138.52	0.18	94.26	131.79	193.40	6.62	250.39
	30 – 60	83.84	79.16	0.25	47.63	87.98	108.90	6.86	136.33
	Total	293.07	283.26	0.63	177.17	281.81	405.53	16.87	513.91
Rabi, 2005 – 06	0 – 15	39.52	38.16	0.08	20.09	31.69	64.75	3.95	93.10
	15 – 30	111.13	108.54	0.42	62.73	101.18	165.60	3.21	247.79
	30 – 60	51.02	50.21	0.21	27.19	49.89	74.76	3.60	116.00
	Total	201.67	196.91	0.65	110.01	182.76	305.11	4.74	456.89
Rabi, 2006 – 07	0 – 15	53.88	52.87	0.42	26.74	48.26	85.13	6.45	116.67
	15 – 30	123.09	120.21	0.22	73.88	118.75	172.32	5.03	224.59
	30 – 60	65.57	63.45	0.13	37.65	64.18	91.70	5.02	120.93
	Total	242.54	236.53	0.74	138.27	231.19	349.15	11.38	462.19

Table 4.8 Biomass of herbaceous layer (kg ha^{-1}) during kharif season at different months of the growing period

Component	Month	Black–gram	Green–gram	LSD (0.05)	Pruning regime: 70% canopy pruning	50% canopy pruning	Control (un–pruned)	LSD (0.05)	Pure crop
Crop biomass	2005								
	Aug.	257.81	238.16	0.78	307.90	294.96	141.09	7.94	608.39
	Sept.	335.29	464.22	1.41	511.34	483.78	204.14	9.35	1159.11
	Oct.	412.82 (72.83)	574.56 (61.31)	1.11 (0.08)	628.39 (85.98)	595.03 (80.15)	257.64 (35.15)	11.26 (6.59)	1674.76 (184.47)
	2006								
	Aug.	220.88	219.54	0.03	276.46	261.61	122.55	9.16	421.92
	Sept.	288.96	421.56	0.20	449.35	437.77	178.65	10.17	1042.29
	Oct.	355.25 (35.42)	499.15 (39.16)	0.25 (7.05)	541.77 (49.10)	513.69 (42.10)	226.14 (20.67)	8.21 (3.76)	1414.36 (122.43)
Weed biomass	2005								
	Aug.	227.74	237.42	0.17	276.41	263.64	157.69	8.25	238.70
	Sept.	277.09	244.41	0.18	310.26	296.72	175.28	7.04	283.36
	Oct.	338.32	352.49	0.28	422.19	387.13	226.89	7.86	371.12
	2006								
	Aug.	174.94	167.42	0.19	199.24	189.14	125.15	6.81	197.04
	Sept.	203.94	214.50	0.06	251.44	240.21	136.00	7.83	231.61
	Oct.	260.45	298.88	0.14	333.53	313.75	191.73	7.77	285.00
Floor litter	2005								
	Aug.	–	–		–	–	–		–
	Sept.	43.79	51.17	0.18	63.93	61.08	17.43	1.22	129.49
	Oct.	67.92	104.52	1.40	110.61	106.33	41.73	1.51	228.69
	2006								
	Aug.	–	–		–	–	–		–
	Sept.	33.17	44.20	0.22	51.22	48.78	16.05	2.45	109.69
	Oct.	52.54	84.90	0.17	88.41	84.16	33.60	3.52	194.69
Root biomass	2005								
	Aug.	42.93	49.09	0.14	57.42	55.31	25.30	3.64	72.07
	Sept.	58.18	72.92	0.34	82.97	80.30	33.37	1.19	144.75
	Oct.	69.86	85.43	0.17	98.48	92.88	41.57	3.13	214.65
	2006								
	Aug.	39.76	40.78	0.20	49.37	47.61	23.84	1.10	63.02
	Sept.	54.13	70.39	0.24	78.55	76.11	32.12	1.10	145.27
	Oct.	69.14	90.77	0.04	98.80	95.66	45.40	1.00	183.57

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

Figures in parentheses are grain yield

difference in biomass accumulation of herbaceous layer between 50 and 70% canopy pruning was very less. Biomass accumulated in crop, weed, floor litter and root was 5.0, 8.0, 4.0 and 6.0% less in 50% canopy pruning as compared to 70% canopy pruning during both the years. Interaction effects of crop and pruning on biomass accumulation were also significant (Table 4.9). Grains were recorded highest in 70% canopy pruning (80.15 and 42.10 kg ha^{-1}) followed by 50% canopy pruning and control during both the years.

The herbaceous biomass accumulation in pure crop (without tree) was comparatively higher than the agrisilviculture system. Pure crop accumulated 92–239, 2–15, 165–184 and 56–176% higher monthly crop, weed, floor litter and root biomass, respectively than the agrisilviculture system.

5.5.2 Rabi season

Changes in biomass with age of herbaceous layer have been given in Table 4.10, which revealed that rate of accumulation in crop biomass was more than 4.0 times higher after one month of sowing in mustard and 5.0 times in wheat. Whereas, the rate of accumulation in weed and root biomass was 1.5 and 3.0 times higher, respectively just after one month of sowing. The senescence of lower leaves was started after 2 months of sowing in mustard and floor litter in March was about 2.4 times higher than February, during both the years. In case of wheat, litter fall was started from March and litter production was more than 3.0 times higher in April than March.

Biomass of herbaceous layer in rabi cropping exhibited significant ($P \leq 0.05$) variation due to pruning and 70% canopy pruning yielded higher biomass as compared to 50% canopy pruning and control (unpruned). The combined effect of pruning and intercrops on herbaceous biomass was also significant (Table 4.11). Wheat gave higher biomass (1615.6 and 1347.41 kg ha^{-1} during 2005–06 and 2006–07, respectively) in 70% canopy pruning than mustard. Although, the variation in biomass was very much obvious due to pruning but variation between intercrops was due to the nature of crops. Grain production was significantly higher in 70% canopy pruning (744.85 and 646.23 kg ha^{-1}) than 50% canopy pruning and control (unpruned) in both the years.

In pure crop (without tree) biomass accumulation of herbaceous layer was comparatively higher than agrisilviculture system. Pure crop accumulated 37–108% higher monthly biomass than agrisilviculture system, except weed biomass.

Table 4.9 Interaction effects of crop and pruning on herbaceous biomass during kharif season.

Component	Treatments	Blackgram			Greengram		
		Aug.	Sept.	Oct.	Aug.	Sept.	Oct.
Crop		2005					
	70% canopy pruning	322.37	417.27	506.30	293.43	605.42	750.48
	50% canopy pruning	308.58	402.37	483.35	281.33	565.20	706.72
	Control (unpruned)	142.47	186.25	248.82	139.72	222.03	266.47
	LSD (0.05)	11.23	13.23	15.93			
		2006					
	70% canopy pruning	277.97	353.61	429.62	274.94	545.08	653.93
	50% canopy pruning	262.68	344.67	413.66	260.54	530.87	613.72
	Control (unpruned)	121.97	168.58	222.47	123.13	188.72	229.80
	LSD (0.05)	NS	14.38	11.60			
Weed		2005					
	70% canopy pruning	263.88	322.30	405.62	288.93	298.22	438.77
	50% canopy pruning	250.63	313.00	383.55	276.65	280.44	390.71
	Control (unpruned)	168.72	195.97	225.80	146.67	154.58	227.98
	LSD (0.05)	11.67	NS	11.11			
		2006					
	70% canopy pruning	208.88	242.57	299.62	189.60	260.32	367.43
	50% canopy pruning	198.29	236.87	286.55	179.99	243.56	340.94
	Control (unpruned)	117.63	132.38	195.19	132.67	139.62	188.28
	LSD (0.05)	9.63	11.07	10.99			
Floor litter		2005					
	70% canopy pruning	–	59.82	88.58	–	68.05	132.63
	50% canopy pruning	–	56.80	85.18	–	65.37	127.48
	Control (unpruned)	–	14.77	30.00	–	20.08	53.46
	LSD (0.05)	–	1.73	2.14	–		
		2006					
	70% canopy pruning	–	43.46	67.85	–	58.98	108.97
	50% canopy pruning	–	42.80	65.78	–	54.75	102.54
	Control (unpruned)	–	13.23	24.00	–	18.87	43.20
	LSD (0.05)	–	3.46	4.98	–		
Root biomass		2005					
	70% canopy pruning	52.54	72.16	87.20	62.30	93.79	109.76
	50% canopy pruning	50.88	69.59	81.27	59.73	91.02	104.50
	Control (unpruned)	25.37	32.79	41.10	25.23	33.95	42.03
	LSD (0.05)	5.14	1.68	4.43			
		2006					
	70% canopy pruning	49.59	66.26	83.74	49.14	90.84	113.85
	50% canopy pruning	47.74	64.20	79.83	47.48	88.02	111.49
	Control (unpruned)	21.96	31.92	43.83	25.71	32.32	46.96
	LSD (0.05)	1.56	1.55	1.41			

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

Table 4.10 Biomass of herbaceous layer (kg ha^{-1}) during rabi season at different months of the growing period

Component	Month	Mustard	Wheat	LSD (0.05)	Pruning regime			LSD (0.05)	Pure crop
					70% canopy pruning	50% canopy pruning	Control (un-pruned)		
	2005 – 06								
Crop biomass	Dec.	269.14	300.91	0.19	342.76	320.40	191.91	50.12	490.95
	Jan.	1084.40	1589.48	0.02	1656.41	1578.80	775.61	94.58	2344.00
	Feb.	1904.14	2056.09	0.14	2427.67	2350.42	1162.26	106.22	3052.21
	March	2283.62	2154.23	0.13	2714.97	2631.22	1310.59	118.34	3475.38
	April	–	2361.56	–	2802.84	2666.19	1615.64	–	3332.80
		(274.75)	(922.47)	(12.88)	(744.85)	(714.23)	(336.75)	(19.89)	(1493.26)
	2006 – 07								
	Dec.	230.53	274.51	0.28	333.27	288.60	135.70	41.15	393.93
	Jan.	812.12	1116.85	0.15	1206.93	1093.95	592.57	30.93	1983.05
	Feb.	1641.04	1881.45	0.52	2294.93	2091.87	896.93	52.23	3054.98
	March	1927.97	1982.65	0.39	2488.79	2272.01	1105.13	95.93	3053.54
	April	–	2098.81	–	2625.20	2323.83	1347.41	–	3197.11
		(203.89)	(783.20)	(26.07)	(646.23)	(571.13)	(236.27)	(77.81)	(1331.83)
	2005 – 06								
Weed biomass	Dec.	206.24	202.78	0.24	224.57	218.79	170.17	33.15	198.42
	Jan.	344.36	327.95	0.63	402.14	385.43	221.04	40.63	340.51
	Feb.	423.20	361.59	0.10	470.56	446.13	260.52	44.10	412.31
	March	470.42	379.81	0.11	508.93	487.17	279.24	33..98	445.99
	April	–	416.48	–	495.97	465.38	288.09	–	401.25
	2005 – 06								
	Dec.	170.28	113.49	0.70	171.99	143.47	110.19	14.58	128.62
	Jan.	235.18	180.11	0.32	270.42	220.98	131.54	27.65	171.14
	Feb.	356.82	226.54	0.67	369.30	334.47	171.28	25.72	227.60
	March	411.36	272.50	0.20	411.11	396.20	218.48	19.66	325.69
	April	–	314.45	–	365.19	340.08	238.08	–	264.47

Continue

Floor litter	2006 – 07								
	Dec.	–	–	–	–	–	–	–	–
	Jan.	–	–	–	–	–	–	–	–
	Feb.	169.51	–	–	212.85	192.30	103.37	–	352.74
	March	409.51	88.49	0.02	313.43	301.47	132.10	28.43	392.07
	April	–	281.83	–	344.67	329.64	171.16	–	461.40
	2005 – 06								
	Dec.	–	–	–	–	–	–	–	–
	Jan.	–	–	–	–	–	–	–	–
	Feb.	162.85	–	–	216.83	182.65	89.06	–	329.12
	March	386.90	69.88	0.15	294.53	276.24	114.40	11.37	384.14
	April	–	254.13	–	303.82	295.87	162.71	–	432.79
Root biomass	2005 – 06								
	Dec.	47.52	51.45	0.17	59.56	53.57	35.33	9.11	70.14
	Jan.	144.23	191.55	0.15	206.21	198.02	99.44	19.01	295.63
	Feb.	234.10	244.16	0.13	291.84	280.91	144.65	26.19	423.34
	March	319.24	287.46	0.20	368.99	358.40	182.66	31.17	503.03
	April	–	314.21	–	371.68	361.27	209.69	–	507.24
	2006 – 07								
	Dec.	40.41	36.60	0.27	50.03	42.32	23.17	4.63	52.92
	Jan.	106.15	129.70	0.23	149.24	132.08	72.46	3.47	215.42
	Feb.	218.40	214.68	0.15	282.71	254.43	112.47	6.56	348.29
	March	276.58	235.54	0.18	324.97	298.41	144.80	11.85	383.18
	April	–	271.84	–	336.51	301.19	177.82	–	496.60

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively
In case of mustard, March represents at harvest whereas in wheat, April represents at harvest
Figures in parentheses are grain yield

Table 4.11 Interaction effects of crop and pruning on biomass (kg ha^{-1}) of herbaceous layer during rabi season

Component	Treatments	Mustard					Wheat				
		Dec.	Jan.	Feb.	March	April	Dec.	Jan.	Feb.	March	April
		2005 – 06									
Crop	70% canopy pruning	330.00	1351.02	2372.85	2842.43	–	355.51	1961.80	2482.49	2587.51	2802.84
	50% canopy pruning	304.08	1329.41	2342.82	2802.90	–	336.72	1828.19	2358.02	2459.53	2666.19
	Control (unpruned)	173.33	572.77	996.75	1205.54	–	210.49	978.45	1327.77	1415.64	1615.64
	LSD (0.05)	NS	NS	150.21	167.36	–					
		2006 – 07									
	70% canopy pruning	316.65	1085.54	2227.64	2504.92	–	349.88	1328.32	2362.23	2472.66	2625.20
	50% canopy pruning	249.30	973.99	1988.77	2263.03	–	327.89	1213.90	2194.97	2280.98	2323.83
	Control (unpruned)	125.65	376.82	706.70	1015.96	–	145.76	808.33	1087.16	1194.30	1347.41
	LSD (0.05)	NS	43.74	73.86	NS	–					
		2005 – 06									
Weed	70% canopy pruning	230.25	413.37	509.51	571.89	–	218.88	390.91	431.60	445.97	495.97
	50% canopy pruning	224.63	396.67	483.43	548.96	–	212.95	374.20	408.82	425.38	465.38
	Control (unpruned)	163.85	223.33	276.67	290.40	–	176.50	218.74	244.37	268.09	288.09
	LSD (0.05)	NS	NS	NS	48.06	–					
		2006 – 07									
	70% canopy pruning	210.45	322.89	475.00	504.51	–	133.53	217.95	263.60	317.70	365.19
	50% canopy pruning	178.15	243.00	428.09	494.94	–	108.79	198.96	240.85	297.47	340.08
	Control (unpruned)	122.24	139.67	167.38	234.62	–	98.14	123.42	175.18	202.34	238.08
	LSD (0.05)	20.61	39.10	36.38	27.80	–					
		2005 – 06									
Floor litter	70% canopy pruning	–	–	212.85	512.85	–	–	–	–	114.01	344.67
	50% canopy pruning	–	–	192.30	492.30	–	–	–	–	110.64	329.64
	Control (unpruned)	–	–	103.37	223.37	–	–	–	–	40.83	171.16
	LSD (0.05)	–	–	–	40.20						

Continue

		2006 – 07									
Floor litter	70% canopy pruning	–	–	216.83	495.69	–	–	–	–	93.37	303.82
	50% canopy pruning	–	–	182.65	468.34	–	–	–	–	84.13	295.87
	Control (unpruned)	–	–	89.06	196.66	–	–	–	–	32.14	162.71
	LSD (0.05)	–	–	–	16.08	–					
Root		2005 – 06									
	70% canopy pruning	58.23	179.68	290.84	396.30	–	60.88	232.73	292.84	341.68	371.68
	50% canopy pruning	52.72	172.40	283.02	385.53	–	54.42	223.64	278.80	331.27	361.27
	Control (unpruned)	31.60	80.61	128.45	175.90	–	39.05	118.27	160.85	189.42	209.69
	LSD (0.05)	NS	NS	NS	NS	–					
		2006 – 07									
	70% canopy pruning	53.71	143.84	296.61	356.51	–	46.34	154.63	268.82	293.42	336.51
	50% canopy pruning	42.75	122.87	262.28	326.50	–	41.89	141.29	246.58	270.32	301.19
	Control (unpruned)	24.79	51.75	96.31	146.72	–	21.56	93.17	128.64	142.88	177.82
	LSD (0.05)	NS	4.91	9.28	16.75	–					

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively

In case of mustard, March represents at harvest whereas in wheat, April represents at harvest

4.6 Carbon accumulation in tree biomass

Changes in carbon accumulation with age of the tree have been given in Table 4.12. The influence of the crop sequence on carbon accumulation in tree was not very much obvious. The carbon content in tree at 5 years age was 12.28 to 12.39 t C ha^{-1} in both the crop sequences. The rate of increase in carbon at 6 years age was 5.47 to 5.74 t C ha^{-1} and at 7 years age the rate was 6.12 to 6.42 t C ha^{-1} in both the crop sequences. However, the annual increment in carbon accumulation was 2.46 to 3.45 t C ha^{-1} $year^{-1}$ at different age of the tree. Of the total carbon accumulation, above and belowground biomass accounted for 68.7% and 31.3%, respectively.

Pruning of tree had significant ($P \leq 0.05$) effect on carbon accumulation. Carbon accumulation in 70% canopy pruning was about 37% less than control (unpruned) at different age of the tree. Carbon accumulation in 50% canopy pruning was higher than 70% canopy pruning and differences in carbon accumulation between these two were about 4 t C ha^{-1} at different age of the tree. Contribution of different tree components in carbon accumulation varied with the amount of pruning. The contribution of main bole was higher in 70% canopy pruning whereas the contribution of branches was higher in 50% canopy pruning and control (unpruned). The carbon accumulation in pure tree (without crop) was less than the trees grown in the agrisilviculture system.

4.7 Carbon in litter biomass

The amount of carbon (kg ha^{-1}) in litter fall during both the years is given in Table 4.13. Carbon in litter biomass was almost equal in both the crop sequences during 2005 – 06. However, it was significantly ($P \leq 0.05$) higher (433.4 kg ha^{-1} $year^{-1}$) in blackgram – mustard than greengram – wheat crop sequence during 2006–07. Among the pruning regimes, total carbon in litter fall was significantly ($P \leq 0.05$) highest (557.22 and 605.22 kg C ha^{-1} $year^{-1}$ during 2005 – 06 and 2006 – 07, respectively) in control (unpruned) followed by 50 and 70% canopy pruning during both the years. In pure tree (without crop), total carbon in litter biomass was comparatively 24% and 21% less than trees in the agrisilviculture system during 2005 – 06 and 2006 – 07, respectively.

4.8 Carbon accumulation in fine and small roots biomass

4.8.1 Carbon accumulation in fine roots

The data on carbon accumulation in fine roots during cropping period in different soil layers is presented in Table 4.14, which revealed that carbon accumulation in fine root

Table 4.12 Carbon accumulation (t ha^{-1}) in A. *procera* at different age in agrisilviculture system

Age (years)	Tree component	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% Canopy pruning	50% Canopy pruning	Control (unpruned)		
5.0	Foliage	1.38	1.37	0.01	1.07	1.39	1.67	0.03	1.47
	Branch	4.08	4.04	NS	1.51	4.24	6.42	0.10	5.19
	Main bole	3.05	3.03	NS	3.28	3.48	2.35	0.02	1.90
	Root	3.88	3.84	0.02	2.52	4.10	4.97	0.09	3.93
	Total	12.39	12.28	0.07	8.38	13.21	15.41	0.29	12.49
5.5	Foliage	1.65	1.61	NS	1.31	1.61	1.97	0.05	1.64
	Branch	4.90	4.77	NS	2.02	4.94	7.55	0.15	5.71
	Main bole	3.66	3.56	NS	4.17	3.89	2.78	0.15	2.12
	Root	4.65	4.53	NS	3.22	4.70	5.86	0.15	4.35
	Total	14.86	14.47	NS	10.72	15.14	18.16	0.49	13.82
6.0	Foliage	2.00	1.96	0.04	1.66	1.92	2.36	0.12	2.01
	Branch	5.98	5.87	0.09	2.83	5.92	9.01	0.42	6.81
	Main bole	4.49	4.37	NS	5.51	4.43	3.34	0.27	2.62
	Root	5.67	5.55	NS	4.30	5.52	7.01	0.37	5.25
	Total	18.14	17.75	NS	14.30	17.79	21.72	1.16	16.69
6.5	Foliage	2.33	2.27	NS	1.86	2.23	2.81	0.07	2.31
	Branch	7.07	6.89	0.34	3.35	6.93	10.66	0.25	7.71
	Main bole	5.18	5.01	NS	6.33	4.97	3.98	0.23	3.04
	Root	6.64	6.45	NS	4.96	6.37	8.31	0.25	6.00
	Total	21.22	20.62	NS	16.50	20.50	25.76	0.79	19.06
7.0	Foliage	2.69	2.61	NS	2.15	2.59	3.20	0.12	2.53
	Branch	8.24	7.99	NS	4.12	8.11	12.12	0.41	8.34
	Main bole	5.95	5.81	NS	7.52	5.56	4.55	0.25	3.34
	Root	7.68	7.46	NS	5.91	7.33	9.47	0.35	6.53
	Total	24.56	23.87	NS	19.70	23.59	29.34	1.11	20.74

biomass was higher during kharif cropping as compared to rabi cropping. Fine roots were quantified upto 60 cm soil depth and 0 – 15 cm soil layer accumulated higher carbon (124.08 to 159.96 kg C ha^{-1}) than 15 – 30 and 30 – 60 cm soil depth in both the crop sequences during kharif cropping. Similar results were also recorded during rabi cropping in both the years.

Among different pruning regimes, control (unpruned) accumulated significantly ($P \leq 0.05$) higher carbon (312.08 to 403.17 kg C ha^{-1} during kharif and 275.38 to 371.18 kg C ha^{-1} during rabi) than 50 and 70% canopy pruning in both the years. Pure tree (without tree) accumulated more carbon as compared to trees grown in the agrisilviculture system. The combined influence of crop sequence and pruning regimes was also seen on the carbon accumulation in fine root biomass (Table 4.15). Control (unpruned) grown with blackgram – mustard crop sequence had accumulated significantly ($P \leq 0.05$) higher amount of total carbon through its fine roots than the unpruned trees with greengram – wheat crop sequence at 0 to 60 cm soil depth. Other pruning regimes with blackgram – mustard crop sequence had also significant differences with greengram – wheat crop sequence.

Table 4.13 Carbon in litter biomass (kg ha^{-1} year^{-1}) of *A. procera* under different treatments

Crop sequence	Year	
	2005 – 06	2006 – 07
Blackgram – mustard	381.83	433.43
Greengram – wheat	381.77	422.15
LSD (0.05)	NS	6.09
Pruning regimes		
70% canopy pruning	221.58	253.85
50% canopy pruning	366.61	424.3
Control 9unpruned)	557.22	605.22
LSD (0.05)	2.54	4.44
Pure tree (without crop)	472.48	515.49

4.8.2 Carbon accumulation in small roots

During kharif and rabi cropping, carbon accumulation in small root biomass have been given in Table 4.16. The perusal of data given in this table revealed that small roots in 15–30 cm soil layer stored higher carbon (59.68 to 67.83 kg C ha^{-1}) than 0–15 and 30–60 cm soil depth during kharif under both the crop sequences. The lowest carbon accumulation was found in 0–15 cm depth in both the crop sequences. Similar pattern of

Table 4.14 Carbon accumulation in fine root biomass (kg ha^{-1}) of *A. procera* during cropping period at different soil depths

Cropping period	Soil depth (cm)	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
Kharif, 2005	0 – 15	126.86	124.08	0.10	111.62	120.17	144.63	1.70	235.36
	15 – 30	80.43	78.34	0.11	65.87	76.15	96.15	1.93	181.53
	30 – 60	47.20	43.27	0.14	29.72	34.69	71.30	1.18	114.07
	Total	254.49	245.69	0.28	207.21	231.01	312.08	3.29	530.96
Kharif, 2006	0 – 15	163.00	159.96	0.21	147.54	155.03	181.88	2.60	288.00
	15 – 30	108.11	107.43	0.08	91.27	100.89	131.16	2.06	157.86
	30 – 60	78.50	75.17	0.22	67.68	72.69	90.13	1.70	142.07
	Total	349.61	342.56	0.50	306.49	328.61	403.17	4.67	587.93
Rabi, 2005 – 06	0 – 15	116.65	110.21	0.63	97.19	111.55	131.55	1.81	221.01
	15 – 30	74.78	65.38	0.12	58.08	66.69	85.48	1.46	179.89
	30 – 60	40.56	35.69	0.19	23.42	32.60	58.35	1.97	93.01
	Total	231.99	211.28	0.71	178.69	210.84	275.38	2.68	493.91
Rabi, 2006 – 07	0 – 15	159.74	147.16	0.19	136.37	147.66	176.31	1.77	281.19
	15 – 30	97.56	94.83	0.20	83.44	90.41	114.74	1.57	156.98
	30 – 60	72.33	63.61	0.39	59.79	64.00	80.12	2.00	140.87
	Total	329.63	305.60	0.56	279.60	302.07	371.17	2.89	579.04

Table 4.15 Interaction effects of crop and pruning on carbon accumulation in fine root biomass (kg ha^{-1}) during cropping period

Treatment	Crop sequence							
	Blackgram – mustard				Greengram – wheat			
	0 – 15	15 – 30	30 – 60	Total	0 – 15	15 – 30	30 – 60	Total
	Kharif, 2005							
70% canopy pruning	115.02	67.07	32.89	214.98	108.22	64.67	26.55	199.44
50% canopy pruning	120.98	77.11	35.63	233.72	119.36	75.18	33.75	228.29
Control (unpruned)	144.60	97.12	73.08	314.80	144.67	95.18	69.52	309.37
LSD (0.05)	2.41	NS	NS	4.65				
	Kharif, 2006							
70% canopy pruning	145.77	90.46	68.46	304.69	149.30	92.08	66.91	308.29
50% canopy pruning	156.89	102.79	74.48	334.16	153.17	98.98	70.90	323.05
Control (unpruned)	186.35	131.08	92.57	410.00	177.42	131.23	87.70	396.35
LSD (0.05)	3.67	2.92	NS	6.61				
	Rabi, 2005 – 06							
70% canopy pruning	97.90	59.65	24.07	181.62	96.49	56.51	22.77	175.77
50% canopy pruning	116.44	70.97	32.94	220.35	106.65	62.40	32.25	201.30
Control (unpruned)	135.60	93.72	64.66	293.98	127.50	77.25	52.04	256.79
LSD (0.05)	2.57	2.07	2.78	3.79				
	Rabi, 2006 – 07							
70% canopy pruning	138.56	86.07	64.99	289.62	134.18	80.81	54.60	269.59
50% canopy pruning	152.00	89.82	68.76	310.58	143.32	91.00	59.24	293.56
Control (unpruned)	188.65	116.80	83.24	388.69	163.97	112.67	77.01	353.65
LSD (0.05)	2.50	2.22	NS	4.08				

carbon accumulation in small root biomass was also observed during rabi cropping. Among the crop sequences, trees with blackgram – mustard recorded significantly ($P \leq 0.05$) higher carbon accumulation through its small roots than greengram – wheat crop sequence. The amount of carbon accumulated in small root biomass during kharif cropping was comparatively more than rabi cropping irrespective of pruning regimes during both the years.

Carbon accumulation in small roots differed significantly ($P \leq 0.05$) among the pruning regimes and was highest in control (unpruned) followed by 50 and 70% canopy pruning. In control (unpruned), carbon accumulation in small root biomass was 44–67% and 129–177% higher than 50 and 70% canopy pruning, respectively during kharif and rabi cropping in both the years. In pure tree (without crop), carbon accumulation in small root biomass was 78 – 129% higher than that of the agrisilviculture system.

4.9 Carbon accumulation in herbaceous layer during kharif and rabi season

4.9.1 Kharif season

Carbon accumulation of herbaceous layer increased with advancement of crop growth and rate of accumulation was higher after one month of sowing (Table 4.17). The increment in carbon accumulation during different months of growing period was almost stable. Generally, carbon accumulation in different components of herbaceous layer was in order of crop > weed > root > floor litter. Among the crops, greengram accumulated significantly ($P \leq 0.05$) higher carbon than blackgram. The carbon accumulation in blackgram just after one month of sowing (August) was 93.32 to 108.92 kg C ha^{-1} and increase in carbon during Sept. and Oct. was about 31 to 36 kg C ha^{-1} and 42 to 65 kg C ha^{-1}, respectively during the study period. In weed biomass, the carbon stored after a month of crop (August) was 71.16 to 92.65 kg C ha^{-1} and rate of increase in Sept. and Oct. was 15 to 25 kg C ha^{-1} and 21 to 22 kg C ha^{-1}, respectively in both the years. The contribution of root in total carbon accumulation was about 10% and the pattern of accumulation during different months was similar to the crop biomass. Similar results were also obtained in greengram during both the years.

Among the pruning regimes, 70% canopy pruning accumulated significantly ($P \leq 0.05$) higher carbon than 50% canopy pruning and control (unpruned). In 70% canopy pruning, monthly carbon accumulation in crop and weed biomass was 3–9% and 59–150% higher than 50% canopy pruning and control (unpruned), respectively. Floor litter was 5% and

Table 4.16 Carbon accumulation in small root biomass (kg ha^{-1}) of *A. procera* during cropping period at different soil depths

Cropping period	Soil depth (cm)	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
Kharif, 2005	0 – 15	25.86	23.47	0.26	11.89	21.37	40.74	1.80	51.89
	15 – 30	62.57	59.68	0.23	41.14	55.90	86.34	1.32	130.14
	30 – 60	32.94	30.86	0.21	17.88	31.32	46.50	1.79	66.55
	Total	121.37	114.01	0.23	70.91	108.59	173.58	3.13	248.58
Kharif, 2006	0 – 15	32.74	31.52	0.26	16.96	29.82	49.62	2.85	61.14
	15 – 30	67.83	66.59	0.09	45.31	63.35	92.97	3.18	120.36
	30 – 60	40.30	38.05	0.12	22.89	42.29	52.35	3.30	65.54
	Total	140.87	136.16	0.30	85.16	135.46	194.94	8.11	247.04
Rabi, 2005 – 06	0 – 15	19.00	18.35	0.04	9.66	15.23	31.12	1.90	44.75
	15 – 30	53.42	52.18	0.20	30.15	48.64	79.60	1.54	119.11
	30 – 60	24.52	24.14	0.10	13.07	23.98	35.94	1.73	55.76
	Total	96.94	94.67	0.31	52.88	87.85	146.66	2.28	219.62
Rabi, 2006 – 07	0 – 15	25.90	25.42	0.20	12.86	23.20	40.92	3.10	56.08
	15 – 30	59.17	57.79	0.10	35.51	57.08	82.84	2.42	107.96
	30 – 60	31.52	30.50	0.06	18.10	30.85	44.08	2.41	58.13
	Total	116.59	113.71	0.35	66.47	111.13	167.84	5.47	222.17

Table 4.17 Carbon accumulation in herbaceous biomass (kg ha^{-1}) during kharif season at different months of the growing period

Component	Month	Black–gram	Green –gram	LSD (0.05)	Pruning regime: 70% canopy pruning	Pruning regime: 50% canopy pruning	Pruning regime: Control (un–pruned)	LSD (0.05)	Pure crop
Crop biomass	2005								
	Aug.	108.92	99.58	0.33	129.44	124.00	59.30	3.33	255.99
	Sept.	144.04	195.53	0.61	217.13	205.46	86.77	3.96	492.56
	Oct.	177.02 (32.01)	240.45 (27.02)	0.47 (0.04)	265.59 (37.83)	251.51 (35.26)	109.10 (15.46)	4.77 (2.90)	708.22 (81.16)
	2006								
	Aug.	93.32	91.79	0.11	116.20	109.96	51.51	3.85	177.24
	Sept.	124.14	177.56	0.08	190.75	185.84	75.96	4.33	442.81
	Oct.	152.33 (15.56)	208.89 (17.26)	0.11 (3.10)	228.95 (21.61)	217.11 (18.53)	95.78 (9.10)	3.48 (1.66)	598.10 (53.87)
Weed biomass	2005								
	Aug.	92.65	103.04	0.07	116.37	111.01	66.14	3.42	100.63
	Sept.	117.13	106.61	0.08	133.16	127.32	75.13	2.98	121.60
	Oct.	139.32	153.33	0.12	178.95	163.95	96.08	3.33	157.22
	2006								
	Aug.	71.16	72.66	0.08	83.63	79.39	52.72	2.87	82.80
	Sept.	86.20	93.57	0.03	108.04	103.18	58.43	3.39	99.61
	Oct.	107.25	130.01	0.05	141.61	133.16	81.14	3.30	120.67
Floor litter	2005								
	Aug.	–	–	–	–	–	–	–	–
	Sept.	18.71	21.33	0.08	26.96	25.76	7.34	0.52	54.61
	Oct.	28.08	41.86	0.56	44.87	43.13	16.91	0.62	92.91
	2006								
	Aug.	–	–		–	–	–		–
	Sept.	14.17	18.42	0.09	21.58	20.55	6.76	1.02	46.24
	Oct.	21.72	34.00	0.07	35.85	34.13	13.61	1.41	79.04
Root biomass	2005								
	Aug.	18.17	20.95	0.06	24.42	23.52	10.76	1.55	30.68
	Sept.	25.00	31.39	0.15	35.69	34.55	14.35	0.51	62.27
	Oct.	30.09	36.98	0.07	42.54	40.12	17.95	1.92	92.73
	2006								
	Aug.	16.83	17.40	0.09	20.98	20.24	10.13	0.47	26.80
	Sept.	23.26	30.30	0.10	33.79	32.74	13.82	0.47	62.50
	Oct.	29.78	39.29	0.02	42.68	41.33	19.61	0.43	79.31

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

Figures in parentheses are carbon in grain

163–267% higher than 50% canopy pruning and control (unpruned), respectively. Carbon accumulation in blackgram grains was significantly ($P \leq 0.05$) higher as compared to greengram in 2005. However, it was significantly higher in greengram than blackgram in 2006. Interaction effects of crop and pruning on carbon accumulation were also significant (Table 4.18). Greengram accumulated higher carbon in all the pruning regimes than blackgram. Although the effect of pruning on carbon accumulation was almost similar in both the crops, the difference in between the crops was due to the different nature of crop.

Carbon accumulation in pure crop (without tree) was comparatively higher than agrisilviculture system. Pure crop (without tree) accumulated 91–239, 2–15, 166–184 and 57–177% higher monthly carbon in crop, weed, floor litter and roots, respectively than the agrisilviculture system.

4.9.2 Rabi season.

Changes in carbon accumulation during rabi season (mustard and wheat) have been given in Table 4.19. The carbon accumulation in wheat crop was significantly ($P \leq 0.05$) higher as compared to mustard throughout the growing period and rate of carbon accumulation in Jan., Feb., March and April was 5.6, 7.0, 7.5 and 9.0 times higher, respectively than the amount of carbon accumulated in Dec. (128.61 kg C ha^{-1}) in 2005 – 06. Similar pattern was also found during 2006 – 07 but the amount of carbon accumulated in crop biomass was comparatively less in 2006 – 07 than 2005 – 06. In case of mustard, rate of accumulation in Jan. was 4.0 times higher than Dec. (114.76 kg C ha^{-1}) but in Feb. and March, rate of accumulation was 7 and 8 times higher than Dec. in 2005 – 06. It indicates that the crop growth during these two months was very fast. Similar pattern was also found during 2006 – 07. The higher weed biomass in mustard crop accumulated significantly ($P \leq 0.05$) higher carbon than wheat crop. The rate of carbon accumulation increases with the weed growth. The increment in carbon accumulation in weed biomass was 32 to 48 kg C ha^{-1} in both the crops during 2005 – 06 and similar results were found during 2006 – 07. The floor litter in mustard and wheat crop was received in last two months of growing period and total amount of carbon in floor litter of mustard crop was higher than wheat crop during both the years. The carbon accumulation in root biomass of herbaceous layer significantly varied between mustard and wheat crop. The contribution of root biomass in carbon accumulation was about 10–12% of the herbaceous layer.

Table 4.18 Interaction effects of crop and pruning on carbon accumulation (kg ha^{-1}) during kharif season

Comp–onent	Treatments	Blackgram			Greengram		
		Aug.	Sept.	Oct.	Aug.	Sept.	Oct.
Crop		2005					
	70% canopy pruning	136.20	179.26	217.10	122.68	255.00	314.08
	50% canopy pruning	130.38	172.86	207.26	117.63	238.06	295.76
	Control (unpruned)	60.19	80.01	106.69	58.42	93.52	111.52
	LSD (0.05)	4.71	5.60	6.75			
		2006					
	70% canopy pruning	117.44	151.91	184.22	114.95	229.59	273.67
	50% canopy pruning	110.98	148.07	177.38	108.93	223.60	256.84
	Control (unpruned)	51.53	72.42	95.40	51.48	79.49	96.17
	LSD (0.05)	5.45	6.13	4.93			
Weed		2005					
	70% canopy pruning	107.35	136.24	167.03	125.40	130.08	190.86
	50% canopy pruning	101.96	132.31	157.95	120.07	122.33	169.96
	Control (unpruned)	68.63	82.84	92.98	63.65	67.43	99.17
	LSD (0.05)	4.83	4.21	4.72			
		2006					
	70% canopy pruning	84.97	102.53	123.38	82.29	113.55	159.83
	50% canopy pruning	80.67	100.12	118.00	78.11	106.24	148.31
	Control (unpruned)	47.85	55.96	80.38	57.58	60.90	81.90
	LSD (0.05)	4.06	4.79	4.66			
Floor litter		2005					
	70% canopy pruning	–	25.56	36.62	–	28.36	53.12
	50% canopy pruning	–	24.27	35.21	–	27.24	51.05
	Control (unpruned)	–	6.31	12.40	–	8.37	21.41
	LSD (0.05)	–	0.73	0.88	–		
		2006					
	70% canopy pruning	–	18.57	28.05	–	24.58	43.64
	50% canopy pruning	–	18.29	27.19	–	22.82	41.07
	Control (unpruned)	–	5.65	9.92	–	7.86	17.30
	LSD (0.05)	–	1.45	2.00	–		
Root biomass		2005					
	70% canopy pruning	22.24	31.01	37.57	26.59	40.37	47.52
	50% canopy pruning	21.54	29.91	35.01	25.49	39.18	45.24
	Control (unpruned)	10.74	14.09	17.71	10.77	14.62	18.20
	LSD (0.05)	2.19	0.72	1.92			
		2006					
	70% canopy pruning	20.99	28.48	36.08	20.97	39.10	49.29
	50% canopy pruning	20.21	27.59	34.39	20.27	37.89	48.26
	Control (unpruned)	9.30	13.72	18.88	10.97	13.92	20.33
	LSD (0.05)	0.66	0.67	0.61			

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

Table 4.19 Carbon accumulation in herbaceous biomass (kg ha^{-1}) during rabi season at different months of the growing period

Component	Month	Mustard	Wheat	LSD (0.05)	Pruning regime			LSD (0.05)	Pure crop
					70% canopy pruning	50% canopy pruning	Control (un–pruned)		
	2005 – 06								
Crop biomass	Dec.	114.76	128.61	0.09	146.33	136.79	81.94	21.39	209.63
	Jan.	485.49	714.47	0.01	743.34	708.47	348.12	42.49	1051.80
	Feb.	850.77	921.75	0.07	1086.54	1051.94	520.29	47.58	1366.04
	March	1007.54	959.49	0.06	1203.28	1166.06	581.20	52.31	1539.92
	April	–	1000.12	–	1187.00	1129.13	684.22	–	1411.44
		(146.91)	(398.14)	(5.55)	(338.27)	(324.50)	(154.80)	(9.16)	(691.52)
	2006 – 07								
	Dec.	98.30	117.33	0.12	142.28	123.22	57.94	17.58	168.18
	Jan.	363.58	502.02	0.07	541.54	490.85	266.02	13.88	889.63
	Feb.	733.22	843.46	0.23	1027.15	936.29	401.56	23.37	1367.20
	March	850.62	883.07	0.17	1103.25	1007.20	490.09	42.43	1353.49
	April	–	888.85	–	1111.77	984.14	570.63	–	1353.98
		(109.02)	(338.03)	(11.52)	(292.90)	(258.40)	(119.27)	(34.09)	(611.57)
Weed biomass	2005 – 06								
	Dec.	84.68	84.50	0.10	92.88	90.48	70.41	13.76	82.06
	Jan.	145.29	139.41	0.27	170.27	163.19	93.59	17.23	144.12
	Feb.	176.98	153.14	0.04	197.93	187.65	109.60	18.58	173.42
	March	196.02	160.66	0.05	213.48	204.34	117.21	14.24	187.09
	April	–	175.13	–	208.56	195.69	121.14	–	168.72
	2005 – 06								
	Dec.	69.92	47.29	0.29	71.03	59.24	45.54	6.00	53.12
	Jan.	99.20	76.56	0.14	114.42	93.54	55.69	11.69	72.41
	Feb.	149.22	95.94	0.28	155.14	140.51	72.09	10.79	95.70
	March	171.41	115.27	0.08	172.31	166.03	91.68	8.21	136.48
	April	–	132.23	–	153.56	143.01	100.11	–	111.21

Continue

Floor litter	2006 – 07								
	Dec.	–	–	–	–	–	–	–	–
	Jan.	–	–	–	–	–	–	–	–
	Feb.	66.79	–	–	83.86	75.77	40.73	–	138.98
	March	163.84	37.20	0.01	126.56	121.74	53.27	11.37	158.20
	April	–	114.87	–	140.49	134.36	69.77	–	188.07
	2005 – 06								
	Dec.	–	–	–	–	–	–	–	–
	Jan.	–	–	–	–	–	–	–	–
	Feb.	64.16	–	–	85.43	71.97	35.09	–	129.67
	March	154.80	29.38	0.06	118.79	111.38	46.10	4.65	155.03
	April	–	103.58	–	123.84	120.60	66.32	–	176.41
Root biomass	2005 – 06								
	Dec.	20.43	22.25	0.07	25.68	23.10	15.24	3.93	30.24
	Jan.	64.69	86.44	0.07	92.81	89.12	44.76	8.56	134.43
	Feb.	105.79	111.53	0.06	132.60	127.63	65.76	11.93	192.34
	March	144.75	131.14	0.09	167.78	162.96	83.08	14.20	228.76
	April	–	132.13	–	156.29	151.91	88.17	–	213.29
	2006 – 07								
	Dec.	17.37	15.82	0.12	21.56	18.24	9.99	2.00	22.82
	Jan.	47.61	58.53	0.10	67.15	59.43	32.63	1.56	96.92
	Feb.	98.70	98.06	0.07	128.42	115.58	51.14	2.98	158.18
	March	125.40	107.45	0.08	147.75	135.68	65.85	5.38	174.21
	April	–	114.31	–	141.50	126.65	74.77	–	208.82

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively
In case of mustard, March represents at harvest whereas in wheat, April represents at harvest
Figures in parentheses are carbon in grain

Carbon accumulation varied significantly ($P \leq 0.05$) due to pruning and 70% canopy pruning accumulated more carbon in herbaceous biomass as compared to 50% canopy pruning and control (unpruned). In 70% canopy pruning, range of variation in carbon accumulation of herbaceous layer (crop, weed and floor litter biomass) was 3–22 and 32–156% higher than 50% canopy pruning and control (unpruned), respectively. Similarly, carbon accumulation in root biomass was 3–18% higher than 50% canopy pruning whereas 69–151% higher than control (unpruned) during both the years. Carbon accumulation in wheat grains was significantly higher than mustard in both the years. Among different pruning regimes, 70% canopy pruning yielded higher grains as well as carbon in both the crops during the study period as compared to 50% canopy pruning and control (unpruned). The combined effect of pruning and crop was significant ($P \leq 0.05$) on carbon accumulation and in 70% canopy pruning, wheat accumulated higher carbon as compared to mustard (Table 4.20).

In pure crop (without tree) carbon accumulation was comparatively higher than agrisilviculture system. Pure crop accumulated 37–108% higher monthly carbon than agrisilviculture system, except weed biomass.

4.10 Nutrient accumulation in tree biomass

The concentration of nutrients (N, P, K, Ca and Mg) in various tree components is shown in Appendix – 13. Nutrient concentration varied considerably among tree components and was highest in leaves and lowest in main bole. Total nutrient concentration generally graded in the following order: leaves > fine root > coarse root > branch > main bole. The accumulation pattern of nutrients followed the temporal pattern of biomass accumulation and increased with tree age (Table 4.21). Total nutrient storage in tree biomass was in the order of N > Ca > K > Mg > P. Among the tree components, nutrient accumulation varied depending on a particular component. N and Ca accumulation was in the order: roots > foliage > branch > main bole; P was in the order: root > branch > main bole > foliage: K was in the order: root > main bole > branch > foliage and Mg was in the order: foliage > branch > root > main bole.

Nutrient accumulation in tree biomass did no exhibit significant variation due to crop sequence, except at 5 years age. However, nutrient accumulation was generally higher in blackgram – mustard as compared to greengram – wheat crop sequence. In both the crop sequences, total N accumulation increased from 341.83 to 681.37 kg ha^{-1}, P from 40.89

Table 4.20 Interaction effects of crop and pruning on carbon accumulation (kg ha^{-1}) in herbaceous layer during rabi season

Component	Treatments	Mustard					Wheat				
		Dec.	Jan.	Feb.	March	April	Dec.	Jan.	Feb.	March	April
		2005 – 06									
Crop	70% canopy pruning	140.71	604.85	1060.19	1254.08	–	151.95	881.83	1112.90	1152.48	1187.00
	50% canopy pruning	129.66	595.18	1046.77	1236.64	–	143.91	821.77	1057.10	1095.48	1129.13
	Control (unpruned)	73.91	256.43	445.35	531.88	–	89.96	439.81	595.24	630.52	684.22
	LSD (0.05)	NS	NS	67.29	73.97	–					
		2006 – 07									
	70% canopy pruning	135.02	486.00	995.31	1105.17	–	149.54	597.08	1058.99	1101.32	1111.77
	50% canopy pruning	106.30	436.05	888.58	998.45	–	140.14	545.65	984.01	1015.95	984.14
	Control (unpruned)	53.58	168.70	315.76	448.24	–	62.30	363.34	487.37	531.94	570.63
	LSD (0.05)	NS	19.64	33.06	NS	–					
		2005 – 06									
Weed	70% canopy pruning	94.54	174.36	213.08	238.31	–	91.21	166.17	182.78	188.65	208.56
	50% canopy pruning	92.23	167.31	202.17	228.75	–	88.74	159.07	173.13	179.94	195.69
	Control (unpruned)	67.28	94.20	115.70	121.01	–	73.55	92.99	103.49	113.40	121.14
	LSD (0.05)	NS	NS	NS	20.14	–					
		2006 – 07									
	70% canopy pruning	86.41	136.19	198.64	210.23	–	55.64	92.65	111.63	134.39	153.56
	50% canopy pruning	73.15	102.50	179.03	206.24	–	45.33	84.58	102.00	125.83	143.01
	Control (unpruned)	50.19	58.91	70.00	97.77	–	40.90	52.46	74.19	85.59	100.11
	LSD (0.05)	8.48	16.53	15.26	11.61	–					
		2005 – 06									
Floor litter	70% canopy pruning	–	–	83.86	205.19	–	–	–	–	47.93	140.49
	50% canopy pruning	–	–	75.77	196.97	–	–	–	–	46.51	134.36
	Control (unpruned)	–	–	40.73	89.37	–	–	–	–	17.16	69.77
	LSD (0.05)	–	–	–	16.09	–					

Continue

Floor litter		2006 – 07									
	70% canopy pruning	–	–	216.83	495.69	–	–	–	–	93.37	303.82
	50% canopy pruning	–	–	182.65	468.34	–	–	–	–	84.13	295.87
	Control (unpruned)	–	–	89.06	196.66	–	–	–	–	32.14	162.71
	LSD (0.05)	–	–	–	6.58	–					
Root		2005 – 06									
	70% canopy pruning	25.03	80.59	131.43	179.68	–	26.33	105.03	133.77	155.87	156.29
	50% canopy pruning	22.66	77.32	127.90	174.80	–	23.53	100.93	127.36	151.13	151.91
	Control (unpruned)	13.58	36.15	58.05	79.75	–	16.89	53.37	73.48	86.41	88.17
	LSD (0.05)	NS	NS	NS	NS	–					
		2006 – 07									
	70% canopy pruning	23.09	64.51	134.04	161.64	–	20.04	69.78	122.79	133.86	141.50
	50% canopy pruning	18.38	55.11	118.53	148.03	–	18.11	63.76	112.64	123.32	126.65
	Control (unpruned)	10.66	23.21	43.52	66.52	–	9.32	42.05	58.76	65.18	74.77
	LSD (0.05)	NS	2.21	4.22	7.61	–					

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS and 120 DAS, respectively

In case of mustard, March represents at harvest whereas in wheat, April represents at harvest

to 81.69 kg ha^{-1}, K from 116.19 to 231.66 kg ha^{-1}, Ca from 271.17 to 540.32 kg ha^{-1} and Mg from 54.91 to 109.67 kg ha^{-1}. On an average the increment in N, P, K, Ca and Mg accumulation in tree biomass was 57.0, 8.0, 23.0, 54.0 and 11.0 kg C ha^{-1} year^{-1}, respectively at 5 years age and reached upto 144.0, 11.0, 32.0, 76.0 and 15.0 kg C ha^{-1} year^{-1} for N, P, K, Ca and Mg, respectively at 7 years age in both the crop sequences with irrespective of pruning treatment.

Pruning exhibited significant ($P \leq 0.05$) influence on nutrient accumulation in tree biomass. Among the pruning regimes, 70% canopy pruning had accumulated lowest whereas control (unpruned) had accumulated highest nutrients (N, P, K, Ca and Mg) in the tree biomass. In Control (unpruned), the accumulation of N, P, K, Ca and Mg was 55–86, 61–97, 42–72, 54–86 and 87–122%, respectively higher than 70% canopy pruning during all the years.

Nutrient accumulation in pure tree (without crop) was comparatively less than the trees in the agrisilviculture system. Pure tree (without crop) accumulates 21–39, 23–41, 23–40, 23–40 and 30–38% less N, P, K, Ca and Mg, respectively than control (unpruned) in the agrisilviculture system. However, nutrient accumulation in pure tree was comparatively higher than 70% canopy pruning.

4.11 Nutrients in litter biomass

The data on total nutrients in litter biomass in both the years have been given in Table 4.22, which revealed that the nutrient content (kg ha^{-1} year^{-1}) of litter biomass was in the order of Ca > N > K > Mg > P. The quantity of nutrients was almost similar in both the crop sequences during 2005 – 06. However, trees intercropped with blackgram – mustard crop sequence gave significantly ($P \leq 0.05$) higher amount of litter and nutrients than greengram – wheat during 2006 – 07. The amount of N, P, K, Ca and Mg return through litter fall was about 12.52 to 14.42, 1.33 to 1.52, 2.65 to 3.02, 15.86 to 18.05, and 1.40 to 1.60 kg ha^{-1} year^{-1} in both the crop sequences during the study period.

Among the pruning regimes, the amount of nutrients (kg ha^{-1} year^{-1}) in litter biomass was significantly ($P \leq 0.05$) highest in control (unpruned) followed by 50 and 70% canopy pruning. In control (unpruned), nutrients were 43–52 and 139–151% higher than 50 and 70% canopy pruning in both the years. In pure tree (without crop), the amount of nutrients in litter biomass was 20 and 24% less than trees grown in the agrisilviculture system in 2005 – 06 and 2006 – 07, respectively.

Table 4.21 Nutrient accumulation in tree components (kg ha^{-1}) of *A. procera* at different age in agrisilviculture system

Nutrients	Tree component	Tree age 5 year							
		Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
N	Foliage	96.47	95.68	0.59	74.49	97.35	116.40	2.23	102.82
	Branch	89.99	89.17	NS	33.38	93.68	141.68	2.16	114.66
	Main bole	53.81	53.42	NS	57.89	61.52	41.43	1.31	33.49
	Root	104.44	103.56	2.44	67.78	110.40	133.81	0.66	105.89
	Total	344.71	341.83	2.09	233.54	362.95	433.32	8.06	356.86
P	Foliage	6.10	6.05	0.04	4.71	6.16	7.36	0.14	6.50
	Branch	12.17	12.05	NS	4.51	12.66	19.15	0.29	15.5
	Main bole	6.15	6.11	NS	6.62	7.03	4.74	0.15	3.83
	Root	16.83	16.68	0.39	10.92	17.79	21.56	0.11	17.06
	Total	41.25	40.89	0.27	26.76	43.64	52.81	0.97	42.89
K	Foliage	19.97	19.81	0.12	15.42	20.15	24.10	0.46	21.29
	Branch	28.5	28.24	NS	10.57	29.67	44.87	0.68	36.31
	Main bole	28.57	28.36	NS	30.74	32.67	22.00	0.70	17.78
	Root	40.12	39.78	0.94	26.04	42.41	51.40	0.25	40.68
	Total	117.16	116.19	0.54	82.77	124.90	142.37	2.74	116.06
Ca	Foliage	56.40	55.94	0.34	43.55	56.91	68.05	0.31	60.11
	Branch	39.5	39.14	NS	14.65	41.12	62.18	0.95	50.32
	Main bole	27.53	27.33	NS	29.62	31.48	21.20	0.67	17.14
	Root	150.02	148.76	3.50	97.37	158.59	192.22	0.95	152.11
	Total	273.45	271.17	1.62	185.19	288.10	343.65	6.39	279.68
Mg	Foliage	22.31	22.13	0.14	17.23	22.52	26.92	0.52	23.78
	Branch	20.16	19.98	NS	7.48	20.99	31.75	0.48	25.69
	Main bole	1.22	1.21	NS	1.31	1.39	0.94	0.03	0.76
	Root	11.69	11.59	0.27	7.58	12.35	14.97	0.07	11.85
	Total	55.38	54.91	0.50	33.60	57.25	74.58	1.30	62.08

Table 4.21 (Continued)

Nutrients	Tree component	Tree age 5.5 year							
		Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% Canopy pruning	50% Canopy pruning	Control (unpruned)		
N	Foliage	115.33	112.23	NS	91.28	112.55	137.51	3.63	114.53
	Branch	108.17	105.35	NS	44.63	109.04	166.61	3.26	126.04
	Main bole	64.71	62.85	NS	73.61	68.65	49.07	2.56	37.49
	Root	125.34	122.02	4.03	86.80	126.50	157.74	NS	117.18
	Total	413.55	402.45	NS	296.32	416.74	510.93	13.34	395.24
P	Foliage	7.30	7.10	NS	5.77	7.12	8.70	0.23	7.24
	Branch	14.62	14.24	NS	6.03	14.74	22.52	0.44	17.04
	Main bole	7.39	7.18	NS	8.41	7.85	5.61	0.29	4.29
	Root	20.19	19.66	0.65	13.98	20.38	25.41	NS	18.88
	Total	49.50	48.18	NS	34.19	50.09	62.24	1.59	47.45
K	Foliage	23.88	23.23	NS	18.90	23.30	28.47	0.75	23.71
	Branch	34.25	33.36	NS	14.13	34.53	52.76	1.03	39.91
	Main bole	34.36	33.37	NS	39.08	36.45	26.05	1.36	19.91
	Root	48.15	46.87	1.55	33.34	48.59	60.59	NS	45.01
	Total	140.64	136.83	NS	105.45	142.87	167.87	4.63	128.54
Ca	Foliage	67.43	65.62	NS	53.37	65.80	80.39	2.12	66.96
	Branch	47.47	46.24	NS	19.59	47.86	73.12	1.43	55.32
	Main bole	33.11	32.16	NS	37.66	35.12	25.11	1.31	19.18
	Root	180.05	175.28	5.79	124.69	181.72	226.59	NS	168.33
	Total	328.06	319.30	NS	235.31	330.50	405.21	10.59	309.79
Mg	Foliage	26.68	25.96	NS	21.11	26.03	31.81	0.84	26.49
	Branch	24.24	23.61	NS	10.00	24.43	37.33	0.73	28.24
	Main bole	1.46	1.42	NS	1.67	1.55	1.11	0.06	0.85
	Root	14.03	13.65	0.45	9.71	14.16	17.65	NS	13.11
	Total	66.41	64.64	NS	42.49	66.17	87.90	2.07	68.69

Table 4.21 (Continued)

Nutrients	Tree component	Tree age 6 year							
		Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
N	Foliage	139.49	136.79	2.61	115.59	133.81	165.03	8.65	139.97
	Branch	131.88	129.55	0.93	62.53	130.66	198.95	0.12	150.27
	Main bole	79.23	7.17	NS	97.30	78.25	59.05	4.80	46.26
	Root	152.65	149.59	NS	115.68	148.81	188.87	9.84	141.45
	Total	503.25	493.10	NS	391.10	491.53	611.90	32.16	477.95
P	Foliage	8.82	8.65	0.17	7.31	8.46	10.44	0.55	8.85
	Branch	17.83	17.51	0.13	8.45	17.66	26.90	1.24	20.31
	Main bole	9.05	8.82	NS	11.12	8.94	6.75	0.55	5.29
	Root	24.59	24.10	NS	18.64	23.98	30.43	1.59	22.79
	Total	60.29	59.08	NS	45.52	59.04	74.52	3.89	57.24
K	Foliage	28.88	28.32	0.54	23.93	27.70	34.17	1.79	28.98
	Branch	41.76	41.02	0.29	19.80	41.38	63.00	2.91	47.58
	Main bole	42.07	40.97	NS	51.66	41.54	31.35	2.55	24.56
	Root	58.64	57.46	NS	44.44	57.16	72.55	3.78	54.34
	Total	171.35	167.77	NS	139.83	167.78	201.07	10.88	155.46
Ca	Foliage	81.55	79.98	1.53	67.58	78.23	96.48	5.06	81.83
	Branch	57.88	56.86	0.41	27.45	57.35	87.32	4.03	65.95
	Main bole	40.54	39.48	NS	49.79	40.04	30.21	2.46	23.67
	Root	219.29	214.89	NS	166.18	213.77	271.31	14.14	203.20
	Total	399.26	391.21	NS	311.00	389.39	485.32	25.53	374.65
Mg	Foliage	32.27	31.64	0.60	26.74	30.95	38.17	2.00	32.38
	Branch	29.55	29.03	1.48	14.01	29.28	44.58	2.06	33.67
	Main bole	1.79	1.75	NS	2.20	1.77	1.34	0.11	1.05
	Root	17.08	16.74	NS	12.95	16.65	21.14	1.10	15.83
	Total	80.69	79.16	NS	55.90	78.65	105.23	5.25	82.93

Table 4.21 (Continued)

Nutrients	Tree component	Tree age 6.5 year							
		Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
N	Foliage	162.82	158.30	NS	130.02	155.63	196.03	5.67	161.33
	Branch	156.15	151.99	3.68	73.96	153.03	235.22	5.56	170.19
	Main bole	91.49	88.40	NS	111.80	87.71	70.32	4.07	53.67
	Root	178.79	173.75	NS	133.47	171.49	223.86	6.56	161.62
	Total	589.25	572.44	NS	449.25	567.86	725.43	15.25	546.81
P	Foliage	10.30	10.01	NS	8.22	9.85	12.40	0.36	10.21
	Branch	21.11	20.55	0.50	10.00	20.69	31.80	0.75	23.01
	Main bole	10.46	10.10	NS	12.78	10.02	8.04	0.47	6.13
	Root	28.81	27.99	NS	21.50	27.63	36.07	1.06	26.04
	Total	70.68	68.65	NS	52.50	68.19	88.31	1.84	65.39
K	Foliage	33.71	32.77	NS	26.92	32.22	40.58	1.17	33.40
	Branch	49.45	48.13	1.16	23.42	48.46	74.49	1.76	53.89
	Main bole	48.58	46.93	NS	59.36	46.57	37.33	2.16	28.50
	Root	68.68	66.74	NS	51.27	65.87	85.99	2.52	62.08
	Total	200.42	194.57	NS	160.97	193.12	238.39	5.29	177.87
Ca	Foliage	95.20	92.55	NS	76.02	90.99	114.61	3.32	94.32
	Branch	68.53	66.17	1.61	32.46	67.16	103.23	2.44	74.69
	Main bole	46.81	45.23	NS	57.21	44.88	35.98	2.08	27.46
	Root	256.84	249.59	NS	191.73	246.34	321.57	9.43	232.17
	Total	467.38	453.54	NS	357.42	449.37	575.39	12.11	428.65
Mg	Foliage	37.66	36.62	NS	30.08	36.00	45.34	1.31	37.32
	Branch	34.99	34.06	0.82	16.57	34.29	52.71	1.25	38.13
	Main bole	2.07	2.00	NS	2.53	1.98	1.59	0.09	1.21
	Root	20.01	19.44	NS	14.94	19.19	25.05	0.73	18.09
	Total	94.73	92.12	NS	64.12	91.46	124.69	2.38	94.75

Table 4.21 (Continued)

Nutrients	Tree component	Tree age 7 year							
		Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
N	Foliage	187.58	182.37	NS	150.36	180.87	223.68	8.30	176.46
	Branch	181.92	176.40	NS	91.00	179.06	267.42	9.14	184.12
	Main bole	105.08	102.52	NS	132.74	98.26	80.39	4.35	58.95
	Root	206.79	201.03	NS	159.26	197.46	255.01	9.48	175.82
	Total	681.37	662.32	NS	533.36	655.65	826.50	30.93	595.35
P	Foliage	11.87	11.54	NS	9.51	11.44	14.15	0.53	11.16
	Branch	24.59	23.85	NS	12.30	24.21	36.15	1.24	24.89
	Main bole	12.01	11.72	NS	15.17	11.23	9.19	0.50	6.74
	Root	33.22	32.39	NS	25.66	31.81	41.08	1.53	28.33
	Total	81.69	79.50	NS	62.64	78.69	100.57	3.74	71.12
K	Foliage	38.83	37.75	NS	31.13	37.45	46.31	1.72	36.53
	Branch	57.61	55.86	NS	28.82	56.70	84.68	2.89	58.31
	Main bole	55.79	54.43	NS	70.48	52.17	42.68	2.31	31.30
	Root	79.43	77.22	NS	61.18	75.85	97.95	3.64	67.54
	Total	231.66	225.26	NS	191.61	222.17	271.62	10.41	193.68
Ca	Foliage	109.67	106.62	NS	87.91	105.75	130.78	4.86	103.17
	Branch	79.84	77.42	NS	39.94	78.59	117.37	4.01	80.81
	Main bole	53.76	52.46	NS	67.92	50.28	41.13	2.23	30.16
	Root	297.05	288.79	NS	228.78	283.66	366.32	13.62	252.56
	Total	540.32	525.29	NS	424.55	518.28	655.60	24.54	466.70
Mg	Foliage	43.39	42.18	NS	34.78	41.84	51.74	1.92	40.82
	Branch	40.76	39.53	NS	20.39	40.12	59.92	2.05	41.26
	Main bole	2.38	2.32	NS	3.00	2.22	1.82	0.10	1.33
	Root	23.14	22.50	NS	17.82	22.10	28.54	1.06	19.67
	Total	109.67	106.53	NS	75.99	106.28	142.02	5.11	103.08

Table 4.22 Nutrients in litter biomass (kg ha^{-1} $year^{-1}$) of *A. procera* in agrisilviculture system

Nutrients	Year	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
N	2005–06	12.53	12.52	NS	7.27	12.03	18.28	0.08	15.50
	2006–07	14.42	13.85	0.20	8.33	13.92	19.86	0.15	16.91
P	2005–06	1.34	1.33	NS	0.78	1.29	1.96	0.01	1.66
	2006–07	1.52	1.48	0.02	0.89	1.49	2.13	0.02	1.81
K	2005–06	2.66	2.65	NS	1.55	2.56	3.89	0.02	3.30
	2006–07	3.02	2.95	0.04	1.77	2.96	4.22	0.03	3.60
Ca	2005–06	15.87	15.86	NS	9.23	15.22	23.14	0.06	19.68
	2006–07	18.05	17.62	0.13	10.60	17.67	25.24	0.13	21.39
Mg	2005–06	1.41	1.40	NS	0.82	1.35	2.06	0.01	1.75
	2006–07	1.60	1.57	0.01	0.94	1.57	2.24	0.01	1.90

4.12 Nutrient accumulation in fine and small root biomass

Total nutrient accumulation in fine (0–2 mm) and small (2–5 mm) root biomass of *A. procera* at 0 – 60 cm soil layer during kharif and rabi cropping is presented in Table 4.23 and 4.24. The amount of nutrient accumulation was in the order of N > Ca > K > P > Mg in fine and small roots. Nutrient accumulation was higher in kharif cropping as compared to rabi cropping during the study period and increased with tree age. Among the crop sequences, blackgram – mustard accumulated significantly ($P \leq 0.05$) higher nutrients in fine and small root biomass than greengram – wheat.

Nutrient accumulation in fine and small roots varied significantly ($P \leq 0.05$) due to pruning. Fine and small roots in control (unpruned) accumulated 28% and 55% higher nutrients than 50% canopy pruning and 42% and 154% higher nutrients than 70% canopy pruning, respectively during the study period. Interaction effects of pruning and crop on nutrient accumulation in fine roots were also significant (Table 4.25). Pure tree (without crop) accumulated 46–80% and 32–68% higher nutrients in fine and small roots, respectively than trees in the agrisilviculture system.

4.13 Nutrient accumulation in herbaceous layer during kharif and rabi season

4.13.1 Kharif season

Nutrient accumulation in herbaceous biomass (above and belowground) during kharif season is shown in Tables 4.26 and 4.27. In herbaceous biomass, nutrient accumulation was in the order of N > K> Ca > P > Mg. However, in grains it was in the order of N > Ca > K > P > Mg. Nutrient content in herbaceous layer (crop + weed + floor litter) increased with advancement of growth and monthly increment in nutrient accumulation varied in blackgram and greengram during both the years. Accumulation of N, Ca and Mg was significantly ($P \leq 0.05$) higher in greengram than blackgram during both the years whereas P and K accumulation was significantly higher in blackgram than greengram.

Nutrient accumulation in herbaceous layer differed significantly ($P \leq 0.05$) due to pruning. Over the entire growing season, 70% canopy pruning had higher nutrient accumulation than did 50% canopy pruning or control (unpruned). In 70% canopy pruning, monthly nutrient accumulation in above ground biomass was 3–7% higher than 50% canopy pruning whereas 86–129% higher than control (unpruned). Similarly in root biomass, 70% canopy pruning accumulates 3–11% and 75–183% higher nutrients than

Table 4.23 Nutrient accumulation in fine root biomass (kg ha^{-1}) of *A. procera* during cropping period at 0 – 60 cm soil depth

Cropping period	Nutrients	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
Kharif, 2005	N	13.57	13.10	0.015	11.04	12.31	16.63	0.18	28.30
	P	1.56	1.51	0.002	1.27	1.42	1.91	0.02	3.26
	K	2.66	2.56	0.003	2.16	2.41	3.26	0.03	5.54
	Ca	9.85	9.51	0.011	8.02	8.94	12.07	0.13	20.54
	Mg	0.78	0.75	0.001	0.64	0.71	0.96	0.01	1.63
Kharif, 2006	N	18.64	18.26	0.027	16.34	17.52	21.49	0.25	31.34
	P	2.14	2.10	0.003	1.88	2.02	2.47	0.03	3.61
	K	3.65	3.57	0.005	3.20	3.43	4.21	0.05	6.13
	Ca	13.53	13.25	0.019	11.86	12.71	15.60	0.18	22.75
	Mg	1.07	1.05	0.002	0.94	1.01	1.24	0.01	1.80
Rabi, 2005 – 06	N	12.37	11.26	0.038	9.53	11.24	14.68	0.14	26.33
	P	1.42	1.30	0.003	1.10	1.29	1.69	0.02	3.03
	K	2.42	2.20	0.007	1.86	2.20	2.87	0.03	5.15
	Ca	8.98	8.17	0.028	6.91	8.16	10.65	0.10	19.11
	Mg	0.71	0.65	0.002	0.55	0.65	0.84	0.01	1.51
Rabi, 2006 – 07	N	17.57	16.29	0.014	14.90	16.10	19.78	0.15	30.66
	P	2.02	1.87	0.002	1.71	1.85	2.28	0.02	3.55
	K	3.44	3.19	0.003	2.92	3.15	3.87	0.03	6.04
	Ca	12.75	11.82	0.010	10.82	11.69	14.36	0.11	22.40
	Mg	1.01	0.94	0.001	0.86	0.93	1.14	0.01	1.78

Table 4.24 Nutrient accumulation in small root biomass (kg ha^{-1}) of *A. procera* during cropping period at 0 – 60 cm soil depth

Cropping period	Nutrients	Crop sequences		LSD (0.05)	Pruning regimes			LSD (0.05)	Pure tree
		Blackgram – mustard	Greengram – wheat		70% canopy pruning	50% canopy pruning	Control (unpruned)		
Kharif, 2005	N	5.40	5.08	0.014	3.16	4.83	7.73	0.14	11.07
	P	0.69	0.65	0.002	0.40	0.62	0.99	0.01	1.41
	K	1.23	1.16	0.003	0.72	1.10	1.77	0.03	2.53
	Ca	4.67	4.39	0.012	2.73	4.18	6.68	0.12	9.57
	Mg	0.35	0.33	0.001	0.20	0.31	0.50	0.01	0.71
Kharif, 2006	N	6.27	6.06	0.014	3.79	6.03	8.68	0.36	11.98
	P	0.80	0.77	0.002	0.48	0.77	1.11	0.05	1.87
	K	1.43	1.39	0.003	0.87	1.38	1.98	0.08	2.72
	Ca	5.42	5.24	0.012	3.28	5.21	7.50	0.31	10.26
	Mg	0.40	0.39	0.001	0.24	0.39	0.56	0.02	0.79
Rabi, 2005 – 06	N	4.32	4.21	0.014	2.35	3.91	6.53	0.10	9.78
	P	0.55	0.54	0.002	0.30	0.50	0.83	0.01	1.25
	K	0.99	0.96	0.003	0.54	0.89	1.49	0.02	2.23
	Ca	3.73	3.64	0.012	2.04	3.38	5.64	0.09	8.45
	Mg	0.28	0.27	0.001	0.15	0.25	0.42	0.01	0.63
Rabi, 2006 – 07	N	5.19	5.06	0.016	2.96	4.95	7.47	0.24	10.18
	P	0.66	0.65	0.002	0.38	0.63	0.95	0.03	1.26
	K	1.19	1.16	0.004	0.68	1.13	1.71	0.06	2.62
	Ca	4.49	4.38	0.014	2.56	4.28	6.46	0.21	8.55
	Mg	0.33	0.34	0.001	0.19	0.32	0.48	0.04	0.64

Table 4.25 Interaction effects of crop and pruning on nutrient accumulation in fine root biomass (kg ha^{-1}) during cropping period at 0 – 60 cm soil depth

Treatment	Crop sequence									
	Blackgram – mustard					Greengram – wheat				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	Kharif, 2005									
70% canopy pruning	11.46	1.32	2.24	8.32	0.66	10.63	1.22	2.08	7.72	0.61
50% canopy pruning	12.46	1.43	2.44	9.04	0.72	12.17	1.40	2.38	8.83	0.70
Control (unpruned)	16.78	1.93	3.28	12.18	0.97	16.49	1.90	3.23	11.97	0.95
LSD (0.05)	0.25	0.03	0.05	0.18	0.01					
	Kharif, 2006									
70% canopy pruning	16.24	1.87	3.18	11.79	0.93	16.43	1.89	3.22	11.93	0.95
50% canopy pruning	17.81	2.05	3.49	12.93	1.02	17.22	1.98	3.37	12.50	0.99
Control (unpruned)	21.85	2.51	4.28	15.86	1.26	21.13	2.43	4.14	15.33	1.22
LSD (0.05)	0.35	0.04	0.07	0.26	0.02					
	Rabi, 2005 – 06									
70% canopy pruning	9.68	1.11	1.90	7.03	0.56	9.37	1.08	1.83	6.80	0.54
50% canopy pruning	11.75	1.35	2.30	8.53	0.68	10.73	1.23	2.10	7.79	0.62
Control (unpruned)	15.67	1.80	3.07	11.37	0.90	13.69	1.57	2.68	9.94	0.79
LSD (0.05)	0.20	0.02	0.04	0.15	0.01					
	Rabi, 2006 – 07									
70% canopy pruning	15.44	1.78	3.02	11.21	0.89	0.82	1.65	2.81	10.43	0.83
50% canopy pruning	16.55	1.90	3.24	12.02	0.95	0.88	1.80	3.06	11.36	0.90
Control (unpruned)	20.72	2.38	4.06	15.04	1.19	1.01	2.17	3.69	13.68	1.08
LSD (0.05)	0.22	0.03	0.04	0.16	0.01					

Table 4.26 Nutrient accumulation in aboveground biomass (kg ha^{-1}) of herbaceous layer (crop + weed + floor litter) at different months of the growing period during kharif season

Nutrient	Month	Black–gram	Green –gram	LSD (0.05)	Pruning regime			LSD (0.05)	Pure crop
					70% canopy pruning	50% canopy pruning	Control (un–pruned)		
	2005								
N	Aug.	8.05	7.59	0.016	9.53	9.12	4.81	0.181	14.52
	Sept.	11.05	12.45	0.030	14.73	14.00	6.52	0.181	27.03
	Oct.	13.04	15.87	0.012	18.16	17.04	8.18	0.238	36.49
	2006								
	Aug.	6.61	6.27	0.005	7.87	7.45	4.01	0.156	10.47
	Sept.	8.93	11.16	0.003	12.54	12.13	5.46	0.212	23.84
	Oct.	10.67	13.60	0.007	15.10	14.29	7.03	0.208	30.27
	2005								
P	Aug.	1.20	0.86	0.002	1.25	1.19	0.64	0.024	1.86
	Sept.	1.57	1.37	0.004	1.83	1.75	0.83	0.022	3.30
	Oct.	1.87	1.78	0.002	2.27	2.15	1.05	0.022	4.55
	2006								
	Aug.	0.98	0.70	0.001	1.02	0.97	0.53	0.021	1.32
	Sept.	1.26	1.23	0.003	1.55	1.50	0.69	0.027	2.89
	Oct.	1.52	1.48	0.001	1.84	1.75	0.91	0.028	3.72
	2005								
K	Aug.	6.26	6.36	0.010	7.64	7.30	3.99	0.154	10.22
	Sept.	6.15	8.40	0.015	9.07	8.61	4.15	0.105	15.22
	Oct.	6.86	8.88	0.007	9.84	9.21	4.53	0.129	18.27
	2006								
	Aug.	5.05	5.16	0.003	6.10	5.78	3.28	0.111	7.65
	Sept.	4.90	7.50	0.002	7.71	7.43	3.47	0.135	13.42
	Oct.	5.54	7.60	0.003	8.14	7.69	3.88	0.114	15.06
	2005								
Ca	Aug.	2.12	2.83	0.004	3.02	2.88	1.54	0.058	4.27
	Sept.	2.85	4.49	0.007	4.61	4.37	2.04	0.059	8.11
	Oct.	3.42	5.07	0.011	5.23	4.90	2.60	0.078	10.05
	2006								
	Aug.	1.73	2.30	0.002	2.44	2.32	1.29	0.044	3.22
	Sept.	2.28	4.02	0.001	3.94	3.80	1.71	0.063	7.19
	Oct.	2.79	4.31	0.001	4.30	4.09	2.25	0.054	8.33
	2005								
Mg	Aug.	0.75	0.76	0.001	0.92	0.88	0.47	0.018	1.32
	Sept.	1.01	1.20	0.003	1.38	1.31	0.62	0.017	2.42
	Oct.	1.19	1.53	0.001	1.70	1.60	0.77	0.022	3.30
	2006								
	Aug.	0.61	0.62	0.0004	0.75	0.71	0.39	0.014	0.97
	Sept.	0.80	1.07	0.0003	1.17	1.13	0.51	0.019	2.13
	Oct.	0.97	1.31	0.001	1.41	1.34	0.66	0.020	2.74

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

Table 4.27 Nutrient accumulation in belowground biomass (kg ha^{-1}) of herbaceous layer at different months of the growing period during kharif season

Nutrient	Month	Black–gram	Green–gram	LSD (0.05)	Pruning regime: 70% canopy pruning	Pruning regime: 50% canopy pruning	Pruning regime: Control (un–pruned)	LSD (0.05)	Pure crop
N	2005								
	Aug.	0.71	0.77	0.002	0.92	0.89	0.41	0.057	1.15
	Sept.	0.94	1.12	0.005	1.31	1.26	0.53	0.019	2.28
	Oct.	0.95	1.30	0.002	1.43	1.35	0.60	0.047	3.12
	2006								
	Aug.	0.66	0.64	0.003	0.79	0.76	0.38	0.018	1.01
	Sept.	0.88	1.08	0.004	1.24	1.20	0.51	0.017	2.29
	Oct.	0.94	1.38	0.001	1.43	1.39	0.65	0.015	2.67
P	2005								
	Aug.	0.06	0.14	0.002	0.12	0.12	0.05	0.010	0.17
	Sept.	0.07	0.19	0.001	0.17	0.16	0.06	0.002	0.29
	Oct.	0.08	0.21	0.0004	0.19	0.18	0.08	0.008	0.42
	2006								
	Aug.	0.06	0.11	0.001	0.10	0.10	0.05	0.002	0.13
	Sept.	0.06	0.19	0.001	0.16	0.15	0.06	0.002	0.30
	Oct.	0.08	0.23	0.0001	0.19	0.19	0.08	0.002	0.36
K	2005								
	Aug.	0.41	0.32	0.001	0.46	0.44	0.20	0.025	0.55
	Sept.	0.52	0.45	0.003	0.61	0.59	0.25	0.009	1.07
	Oct.	0.56	0.44	0.001	0.63	0.59	0.27	0.017	1.36
	2006								
	Aug.	0.38	0.27	0.001	0.40	0.38	0.19	0.009	0.50
	Sept.	0.48	0.44	0.002	0.58	0.56	0.24	0.008	1.06
	Oct.	0.55	0.46	0.001	0.63	0.61	0.30	0.006	1.16
Ca	2005								
	Aug.	0.17	0.29	0.001	0.29	0.27	0.12	0.021	0.38
	Sept.	0.23	0.42	0.002	0.41	0.40	0.16	0.006	0.72
	Oct.	0.27	0.49	0.001	0.48	0.46	0.20	0.018	1.06
	2006								
	Aug.	0.16	0.24	0.001	0.24	0.23	0.12	0.005	0.31
	Sept.	0.21	0.41	0.001	0.39	0.38	0.16	0.006	0.73
	Oct.	0.27	0.52	0.0001	0.49	0.47	0.22	0.005	0.91
Mg	2005								
	Aug.	0.06	0.07	0.0002	0.08	0.08	0.04	0.005	0.11
	Sept.	0.08	0.09	0.014	0.11	0.10	0.05	0.010	0.19
	Oct.	0.10	0.12	0.002	0.14	0.13	0.06	0.004	0.30
	2006								
	Aug.	0.06	0.06	0.003	0.07	0.07	0.04	0.002	0.09
	Sept.	0.08	0.08	0.016	0.10	0.09	0.05	0.011	0.18
	Oct.	0.10	0.13	0.0001	0.14	0.13	0.06	0.001	0.26

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

50% canopy pruning and control (unpruned), respectively. Nutrient accumulation in grains was significantly ($P \leq 0.05$) higher in blackgram than greengram. However in 2006, N and P were higher in greengram (Table 4.28). Interaction effects of crop and pruning on nutrient accumulation in herbaceous biomass (above and belowground) were also significant (Tables 4.29 and 4.30). In pure crop (without tree) nutrient accumulation in above and belowground biomass of herbaceous layer was 51–152% and 20–118%, respectively higher than in the agrisilviculture system.

4.13.2 Rabi season

Nutrient accumulation in herbaceous biomass (above and belowground) during rabi season have been given in Table 4.31 and 4.32. The nutrient accumulation varied significantly ($P \leq 0.05$) in herbaceous biomass of mustard and wheat crop but variation was due to the varying nature of crops. However, the pattern in nutrient accumulation during different months of growing period showed that monthly nutrient accumulation increased with advancement of crop growth, except N in wheat which increases upto 2nd month after sowing and then slightly declined. In aboveground biomass of herbaceous layer, nutrient accumulation was in the order of N > K> Ca > P > Mg. However, in grain it was in the order of N > Ca > K > P > Mg. The order of nutrient accumulation in root biomass was similar to the aboveground biomass of herbaceous layer. On an average N, K, Ca, P and Mg stored in aboveground biomass of herbaceous layer at harvest were 43.06, 53.76, 17.74, 10.68 and 10.28 kg ha^{-1}, respectively in both the crops. Monthly increment of nutrients varied from 8.46 to 10.76 kg ha^{-1} for N, 1.75 to 1.85 kg ha^{-1} for P, 8.61 to 8.53 kg ha^{-1} for K, 2.77 to 4.43 kg ha^{-1} for Ca and 1.62 to 2.5 kg ha^{-1} for Mg in mustard crop during 2005 – 06. However, nutrient accumulation in different months and their increment was less during 2006 – 07 as compared to 2005 – 06. In case of wheat, the increment in nutrient accumulation was more or less similar to mustard crop but N, P, Ca and Mg were higher in mustard than wheat and only K was higher in wheat than mustard. Nutrient accumulation in grains was significantly higher in wheat than mustard, except Mg which was higher in mustard than wheat (Table 4.33).

Nutrient accumulation varied significantly ($P \leq 0.05$) among pruning regimes and was higher in 70% canopy pruning than 50% canopy pruning and control (unpruned). In 70% canopy pruning, monthly nutrient accumulation in above ground biomass was 3–20% higher than 50% canopy pruning whereas 56–175% higher than control (unpruned). Similarly in root biomass, it was 3–22% and 67–181% higher than 50% canopy pruning

Table 4.28 Nutrients in grain yield (kg ha^{-1}) of intercrops during kharif season.

Nutrient	Blackgram	Greengram	LSD (0.05)	Pruning regime			LSD (0.05)	Pure crop
				70% canopy pruning	50% canopy pruning	Control (unpruned)		
	2005							
N	2.30	1.89	0.003	2.68	2.50	1.10	0.20	5.75
P	0.34	0.28	0.0004	0.40	0.37	0.16	0.03	0.85
K	0.70	0.46	0.001	0.74	0.69	0.31	0.05	1.58
Ca	1.36	0.86	0.015	1.42	1.32	0.59	0.10	3.03
Mg	0.12	0.09	0.0001	0.13	0.12	0.05	0.01	0.28
	2006							
N	1.12	1.21	0.22	1.53	1.31	0.64	0.12	3.81
P	0.16	0.18	0.03	0.23	0.19	0.09	0.02	0.56
K	0.34	0.29	0.06	0.41	0.36	0.18	0.03	1.04
Ca	0.66	0.55	0.12	0.79	0.68	0.34	0.05	1.98
Mg	0.06	0.06	0.01	0.07	0.06	0.03	0.01	0.19

Table 4.29 Interaction effects of crop and pruning on nutrient accumulation in aboveground biomass (kg ha^{-1}) of herbaceous layer (crop + weed + floor litter) at different months of the growing period during kharif season

Nutrient	Treatments	Blackgram			Greengram		
		Aug.	Sept.	Oct.	Aug.	Sept.	Oct.
		2005					
N	70% canopy pruning	9.77	13.51	15.95	9.30	15.96	20.37
	50% canopy pruning	9.32	13.04	15.18	8.91	14.95	18.90
	Control (unpruned)	5.06	6.60	8.00	4.55	6.43	8.36
	LSD (0.05)	0.26	0.25	0.34			
		2006					
	70% canopy pruning	8.16	10.87	12.76	7.58	14.22	17.44
	50% canopy pruning	7.72	10.61	12.26	7.18	13.66	16.31
	Control (unpruned)	3.95	5.30	7.01	4.06	5.61	7.05
	LSD (0.05)	0.22	0.30	0.29			
P		2005					
	70% canopy pruning	1.45	1.91	2.28	1.05	1.76	2.26
	50% canopy pruning	1.38	1.85	2.17	1.01	1.65	2.13
	Control (unpruned)	0.76	0.95	1.15	0.52	0.71	0.95
	LSD (0.05)	0.03	0.03	0.03			
		2006					
	70% canopy pruning	1.20	1.53	1.82	0.85	1.56	1.87
	50% canopy pruning	1.14	1.50	1.75	0.80	1.50	1.76
	Control (unpruned)	0.59	0.76	1.01	0.46	0.62	0.81
	LSD (0.05)	0.03	0.04	0.04			
K		2005					
	70% canopy pruning	7.50	7.47	8.33	7.78	10.67	11.36
	50% canopy pruning	7.15	7.21	7.92	7.45	10.01	10.50
	Control (unpruned)	4.14	3.76	4.26	3.84	4.53	4.79
	LSD (0.05)	0.22	0.15	0.18			
		2006					
	70% canopy pruning	6.17	5.95	6.57	6.03	9.47	9.70
	50% canopy pruning	5.84	5.81	6.31	5.72	9.05	9.07
	Control (unpruned)	3.12	2.94	3.72	3.44	3.99	4.03
	LSD (0.05)	0.16	0.19	0.16			
Ca		2005					
	70% canopy pruning	2.56	3.47	4.18	3.47	5.74	6.28
	50% canopy pruning	2.44	3.35	3.97	3.32	5.39	5.84
	Control (unpruned)	1.37	1.73	2.11	1.71	2.35	3.09
	LSD (0.05)	0.08	0.08	0.11			
		2006					
	70% canopy pruning	2.13	2.77	3.32	2.76	5.11	5.28
	50% canopy pruning	2.01	2.70	3.19	2.62	4.90	4.99
	Control (unpruned)	1.05	1.36	1.85	1.52	2.06	2.65
	LSD (0.05)	0.06	0.09	0.08			

Continue

Mg		2005					
	70% canopy pruning	0.91	1.22	1.45	0.93	1.53	1.96
	50% canopy pruning	0.87	1.18	1.38	0.90	1.43	1.81
	Control (unpruned)	0.48	0.61	0.73	0.46	0.63	0.82
	LSD (0.05)	0.03	0.02	0.03			
		2006					
	70% canopy pruning	0.75	0.98	1.15	0.74	1.36	1.67
	50% canopy pruning	0.71	0.95	1.11	0.70	1.30	1.56
	Control (unpruned)	0.37	0.48	0.64	0.41	0.55	0.69
	LSD (0.05)	0.02	0.03	0.03			

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively

Table 4.30 Interaction effects of crop and pruning on nutrient accumulation in belowground biomass (kg ha^{-1}) of herbaceous layer at different months of the growing period during kharif season

Nutrient	Treatments	Blackgram			Greengram		
		Aug.	Sept.	Oct.	Aug.	Sept.	Oct.
		2005					
N	70% canopy pruning	0.867	1.169	1.186	0.972	1.444	1.668
	50% canopy pruning	0.840	1.127	1.105	0.932	1.402	1.588
	Control (unpruned)	0.419	0.531	0.559	0.394	0.523	0.639
	LSD (0.05)	0.025	0.024	0.021			
		2006					
	70% canopy pruning	0.818	1.073	1.139	0.767	1.399	1.731
	50% canopy pruning	0.788	1.040	1.086	0.741	1.355	1.695
	Control (unpruned)	0.362	0.517	0.596	0.401	0.498	0.714
	LSD (0.05)	0.080	0.027	0.067			
P		2005					
	70% canopy pruning	0.073	0.087	0.103	0.173	0.248	0.275
	50% canopy pruning	0.071	0.084	0.096	0.166	0.240	0.262
	Control (unpruned)	0.035	0.039	0.048	0.070	0.090	0.106
	LSD (0.05)	0.003	0.003	0.003			
		2006					
	70% canopy pruning	0.069	0.080	0.099	0.137	0.240	0.286
	50% canopy pruning	0.066	0.077	0.094	0.132	0.232	0.280
	Control (unpruned)	0.031	0.038	0.052	0.071	0.085	0.118
	LSD (0.05)	0.014	0.003	0.011			
K		2005					
	70% canopy pruning	0.500	0.641	0.699	0.412	0.580	0.562
	50% canopy pruning	0.484	0.619	0.652	0.395	0.562	0.535
	Control (unpruned)	0.242	0.291	0.330	0.167	0.210	0.215
	LSD (0.05)	0.013	0.011	0.009			
		2006					
	70% canopy pruning	0.472	0.589	0.672	0.325	0.561	0.583
	50% canopy pruning	0.454	0.571	0.640	0.314	0.544	0.571
	Control (unpruned)	0.209	0.284	0.352	0.170	0.200	0.240
	LSD (0.05)	NS	0.013	NS			
Ca		2005					
	70% canopy pruning	0.209	0.285	0.338	0.363	0.543	0.627
	50% canopy pruning	0.202	0.275	0.315	0.348	0.527	0.597
	Control (unpruned)	0.101	0.130	0.159	0.147	0.197	0.240
	LSD (0.05)	0.007	0.008	0.007			
		2006					
	70% canopy pruning	0.197	0.262	0.325	0.286	0.526	0.650
	50% canopy pruning	0.190	0.254	0.310	0.276	0.510	0.637
	Control (unpruned)	0.087	0.126	0.170	0.150	0.187	0.268
	LSD (0.05)	0.029	0.008	0.025			

Continue

Mg		2005					
	70% canopy pruning	0.076	0.103	0.120	0.093	0.117	0.155
	50% canopy pruning	0.074	0.100	0.112	0.089	0.103	0.147
	Control (unpruned)	0.037	0.047	0.057	0.038	0.049	0.059
	LSD (0.05)	0.002	NS	0.002			
		2006					
	70% canopy pruning	0.072	0.095	0.116	0.073	0.109	0.161
	50% canopy pruning	0.069	0.092	0.110	0.071	0.095	0.157
	Control (unpruned)	0.032	0.046	0.060	0.038	0.047	0.066
	LSD (0.05)	0.008	0.015	0.006			

Aug., Sept. and Oct. represents 30 DAS, 60 DAS and at harvest, respectively,

Table 4.31 Nutrient accumulation in aboveground biomass (kg ha^{-1}) of herbaceous layer (crop + weed + floor litter) at different months of the growing period during rabi season

Nutrient	Month	Mustard	Wheat	LSD (0.05)	Pruning regime			LSD (0.05)	Pure crop
					70% canopy pruning	50% canopy pruning	Control (un-pruned)		
N	2005 – 06								
	Dec.	8.46	7.88	0.004	9.52	9.03	5.96	0.911	11.78
	Jan.	25.66	31.92	0.011	35.46	33.84	17.06	2.041	46.88
	Feb.	37.87	30.20	0.002	41.68	40.24	20.18	1.752	50.67
	March	43.06	27.53	0.003	43.24	41.90	20.74	1.792	53.09
	April	–	31.12	–	37.05	35.19	21.13	–	42.48
	2006 – 07								
	Dec.	7.14	6.29	0.016	8.64	7.40	4.10	0.787	9.07
	Jan.	18.83	21.80	0.005	25.64	22.82	12.47	0.622	38.00
	Feb.	32.71	26.45	0.013	38.60	35.01	15.13	0.919	48.43
	March	36.94	24.36	0.008	38.86	35.77	17.32	1.562	45.81
	April	–	27.09	–	33.46	30.04	17.78	–	39.36
P	2005 – 06								
	Dec.	1.16	1.06	0.001	1.29	1.22	0.81	0.126	1.57
	Jan.	3.51	3.99	0.001	4.62	4.41	2.21	0.264	6.10
	Feb.	6.00	4.94	0.0004	6.70	6.46	3.25	0.290	8.18
	March	7.38	5.26	0.0004	7.74	7.49	3.73	0.291	9.53
	April	–	10.68	–	12.87	12.26	6.91	–	15.92
	2006 – 07								
	Dec.	0.98	0.82	0.002	1.16	0.98	0.56	0.097	1.21
	Jan.	2.58	2.70	0.001	3.34	2.98	1.60	0.078	4.98
	Feb.	5.20	4.32	0.002	6.20	5.62	2.45	0.143	7.82
	March	6.35	4.67	0.001	6.98	6.43	3.12	0.269	8.28
	April	–	9.46	–	11.52	10.73	6.13	–	14.87
K	2005 – 06								
	Dec.	8.61	9.93	0.004	10.72	10.20	6.89	0.929	13.01
	Jan.	24.13	37.26	0.011	37.76	35.97	18.36	2.378	49.06
	Feb.	30.08	45.14	0.003	45.84	44.01	22.97	2.176	55.25
	March	34.12	46.48	0.005	49.07	47.28	24.55	1.540	59.16
	April	–	53.76	–	64.02	60.82	36.43	–	73.65
	2006 – 07								
	Dec.	7.25	7.63	0.018	9.51	8.15	4.66	0.836	9.77
	Jan.	17.68	25.22	0.008	26.92	23.99	13.43	0.651	39.04
	Feb.	26.00	39.40	0.016	42.11	38.42	17.57	1.021	52.01
	March	29.39	41.15	0.008	44.41	40.95	20.45	1.449	52.13
	April	–	46.83	–	57.80	51.97	30.71	–	68.28

Continued

Ca	2005 – 06								
	Dec.	2.77	1.00	0.001	2.20	2.09	1.37	0.262	2.54
	Jan.	8.26	3.72	0.004	7.39	7.14	3.47	0.336	9.83
	Feb.	14.08	4.56	0.0002	11.47	11.12	5.37	0.517	14.02
	March	17.74	4.81	0.0004	13.90	13.53	6.41	0.664	17.26
	April	–	5.56	–	6.62	6.29	3.77	–	7.60
	2005 – 06								
	Dec.	2.34	0.77	0.005	2.01	1.68	0.97	0.164	2.06
	Jan.	6.07	2.51	0.001	5.58	4.89	2.40	0.164	8.30
	Feb.	12.18	3.97	0.003	10.70	9.62	3.90	0.279	13.43
	March	15.29	4.26	0.004	12.47	11.48	5.37	0.594	14.74
	April	–	4.84	–	5.98	5.37	3.18	–	7.04
Mg	2006 – 07								
	Dec.	1.62	0.58	0.001	1.29	1.22	0.80	0.153	1.48
	Jan.	4.83	2.14	0.002	4.29	4.15	2.02	0.195	5.70
	Feb.	7.88	2.60	0.0002	6.45	6.26	3.01	0.262	7.79
	March	10.28	2.71	0.0002	8.01	7.79	3.69	0.386	9.95
	April	–	3.12	–	3.72	3.53	2.12	–	4.26
	2005 – 06								
	Dec.	1.37	0.44	0.003	1.18	0.98	0.57	0.096	1.20
	Jan.	3.54	1.44	0.003	3.24	2.84	1.39	0.096	4.81
	Feb.	6.79	2.26	0.002	5.99	5.40	2.18	0.169	7.47
	March	8.85	2.40	0.002	7.18	6.61	3.09	0.344	8.48
	April	–	2.72	–	3.35	3.01	1.78	–	3.94

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively.

In case of mustard, March represents at harvest whereas in wheat, April represents at harvest

Table 4.32 Nutrient accumulation in belowground biomass (kg ha^{-1}) of herbaceous layer at different months of the growing period during rabi season

Nutrient	Month	Mustard	Wheat	LSD (0.05)	Pruning regime 70% canopy pruning	50% canopy pruning	Control (un–pruned)	LSD (0.05)	Pure crop
N	2005 – 06								
	Dec.	0.80	0.91	0.003	1.02	0.92	0.61	0.158	1.21
	Jan.	2.37	3.31	0.002	3.49	3.35	1.68	0.324	5.06
	Feb.	3.58	4.08	0.002	4.67	4.49	2.33	0.429	6.77
	March	4.76	3.05	0.003	4.76	4.63	2.31	0.358	6.45
	April	–	3.27	–	3.87	3.76	2.18	–	5.28
	2006 – 07								
	Dec.	0.68	0.64	0.005	0.86	0.73	0.40	0.080	0.91
	Jan.	1.74	2.24	0.004	2.52	2.23	1.23	0.058	3.63
	Feb.	3.34	3.59	0.003	4.51	4.07	1.81	0.105	5.55
	March	4.12	2.50	0.002	4.21	3.87	1.85	0.167	4.97
	April	–	2.89	–	3.50	3.13	1.85	–	5.16
P	2005 – 06								
	Dec.	0.09	0.08	0.0003	0.11	0.10	0.06	0.012	0.12
	Jan.	0.27	0.27	0.0003	0.33	0.32	0.16	0.030	0.48
	Feb.	0.43	0.34	0.0002	0.47	0.45	0.23	0.040	0.68
	March	0.57	0.40	0.0004	0.59	0.57	0.29	0.045	0.80
	April	–	0.42	–	0.50	0.48	0.28	–	0.68
	2006 – 07								
	Dec.	0.08	0.06	0.00004	0.09	0.08	0.04	0.008	0.09
	Jan.	0.20	0.18	0.00004	0.24	0.22	0.11	0.006	0.36
	Feb.	0.40	0.30	0.00002	0.46	0.41	0.18	0.011	0.56
	March	0.49	0.33	0.00003	0.52	0.48	0.23	0.020	0.61
	April	–	0.36	–	0.45	0.40	0.24	–	0.67
K	2005 – 06								
	Dec.	0.75	0.43	0.002	0.71	0.64	0.41	0.103	0.83
	Jan.	2.24	1.50	0.003	2.31	2.22	1.09	0.201	3.29
	Feb.	3.45	1.71	0.001	3.17	3.06	1.51	0.250	4.61
	March	4.63	2.00	0.003	4.06	3.94	1.93	0.273	5.45
	April	–	1.61	–	1.90	1.85	1.07	–	2.60
	2006 – 07								
	Dec.	0.64	0.30	0.002	0.62	0.51	0.29	0.051	0.64
	Jan.	1.65	1.02	0.004	1.73	1.51	0.77	0.044	2.52
	Feb.	3.21	1.50	0.001	3.13	2.79	1.16	0.076	3.89
	March	4.01	1.64	0.002	3.60	3.30	1.56	0.157	4.26
	April	–	1.39	–	1.72	1.54	0.91	–	2.54
Ca	2005 – 06								
	Dec.	0.27	0.09	0.001	0.22	0.19	0.12	0.032	0.25
	Jan.	0.80	0.33	0.001	0.70	0.67	0.33	0.062	0.99
	Feb.	1.28	0.40	0.001	1.03	1.00	0.48	0.080	1.51
	March	1.74	0.46	0.001	1.35	1.32	0.63	0.085	1.81
	April	–	0.50	–	0.59	0.58	0.34	–	0.81

Continue

Ca	2005 – 06								
	Dec.	0.23	0.06	0.001	0.19	0.16	0.09	0.016	0.20
	Jan.	0.59	0.22	0.001	0.53	0.46	0.22	0.015	0.79
	Feb.	1.20	0.35	0.00004	1.03	0.92	0.37	0.027	1.29
	March	1.51	0.38	0.001	1.21	1.11	0.51	0.058	1.43
	April	–	0.43	–	0.54	0.48	0.28	–	0.79
Mg	2006 – 07								
	Dec.	0.16	0.05	0.0004	0.13	0.11	0.07	0.019	0.15
	Jan.	0.47	0.19	0.001	0.41	0.39	0.19	0.036	0.58
	Feb.	0.74	0.22	0.003	0.60	0.58	0.28	0.046	0.87
	March	1.00	0.25	0.001	0.77	0.75	0.36	0.048	1.03
	April	–	0.27	–	0.32	0.31	0.18	–	0.44
	2005 – 06								
	Dec.	0.13	0.04	0.0003	0.11	0.09	0.05	0.009	0.11
	Jan.	0.35	0.13	0.001	0.31	0.27	0.13	0.009	0.46
	Feb.	0.69	0.20	0.0002	0.59	0.53	0.21	0.016	0.74
	March	0.87	0.21	0.001	0.69	0.63	0.29	0.033	0.82
	April	–	0.24	–	0.29	0.26	0.15	–	0.43

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively.

In case of mustard, March represents at harvest whereas in wheat, April represents at harvest

Table 4.33 Nutrients in grain yield (kg ha^{-1}) of intercrops during rabi season

Nutrients	Mustard	Wheat	LSD (0.05)	Pruning regime			LSD (0.05)	Pure crop
				70% canopy pruning	50% canopy pruning	Control (unpruned)		
	2005 – 06							
N	8.54	17.25	0.24	15.95	15.31	7.43	0.45	33.58
P	1.55	3.63	0.05	3.21	3.08	1.48	0.09	6.65
K	4.19	7.08	0.10	6.95	6.68	3.28	0.20	14.92
Ca	4.20	9.87	0.14	8.72	8.37	4.03	0.24	18.08
Mg	0.74	0.60	0.01	0.82	0.79	0.41	0.03	1.90
	2006 – 07							
N	6.34	14.65	0.52	13.77	12.11	5.60	1.53	29.33
P	1.15	3.09	0.11	2.78	2.45	1.13	0.02	5.85
K	3.11	6.01	0.22	5.99	5.26	2.44	0.65	12.93
Ca	3.12	8.38	0.29	7.54	6.64	3.07	0.86	15.89
Mg	0.55	0.51	0.02	0.70	0.61	0.28	0.07	1.59

and control (unpruned), respectively. Interaction effects of crop and pruning on nutrient accumulation on herbaceous layer (above and belowground) were also significant (Table 4.34 and 4.35). Nutrient accumulation in grains was also significantly higher in 70% canopy as compared to 50% canopy pruning and control (unpruned). Interaction effect of crop and pruning on nutrient accumulation in grains was also significant (Table 4.36).

In pure crop (without tree), nutrient accumulation in aboveground biomass was 31–93% higher than agrisilviculture system whereas in root biomass it was 29–96% than agrisilviculture system.

4.14 Growth, yield and yield attributing characters of intercrops (kharif and rabi)

4.14.1 Kharif crop (blackgram and greengram)

The growth and yield attributing characters of blackgram and greengram are presented in Table 4.37 and 4.38. Growth and yield attributing characters of both the crops viz. plant population, plant height, branches plant^{-1}, pods plant^{-1}, grains pod^{-1}, test weight and grain yield exhibited significant ($P \leq 0.05$) variation due to pruning and value of these characters were higher in 70% canopy pruning than 50% canopy pruning and control (unpruned). In pure crop (without tree), growth and yield attributing characters were comparatively better than agrisilviculture system.

The data on grain yield have been given in Table 4.39, which indicates that yield performance of blackgram and greengram was higher in 2005 than 2006. Among the pruning regimes, grain yield of both the crops was significantly ($P \leq 0.05$) higher in 70% canopy pruning as compared to 50% canopy pruning and control (unpruned). In blackgram, grain yield was 92.63 and 45.67 kg ha^{-1} in 70% canopy pruning, 85.54 and 40.40 kg ha^{-1} in 50% canopy pruning and 40.45 and 20.20 kg ha^{-1} in control (unpruned) during 2005 and 2006, respectively. Similarly in greengram, grain yield was 79.33 and 52.53 kg ha^{-1}, 74.77 and 43.80 kg ha^{-1} and 29.84 and 21.15 kg ha^{-1} in 70% canopy pruning, 50% canopy pruning and control (unpruned) in 2005 and 2006, respectively. After converting the blackgram grain yield equivalent to greengram, the grain yield of both the crops was almost similar to each other. In pure crop, grain yield of both the crops was recorded 168–226% higher than in the agrisilviculture system.

4.14.2 Rabi crop (mustard and wheat)

The data on growth and yield attributing characters of mustard and wheat are presented in Table 4.40 and 4.41. Growth and yield attributing characters of both the crops differed

Table 4.34 Interaction effects of crop and pruning on nutrient accumulation in aboveground biomass (kg ha^{-1}) of herbaceous layer (crop + weed + floor litter) at different months of the growing period during rabi season

Nutrient	Treatments	Mustard					Wheat				
		Dec.	Jan.	Feb.	March	April	Dec.	Jan.	Feb.	March	April
		2005 – 06									
N	70% canopy pruning	9.99	31.70	46.96	53.45	–	9.05	39.22	36.40	33.02	37.05
	50% canopy pruning	9.41	31.02	45.91	52.38	–	8.64	36.67	34.57	31.43	35.19
	Control (unpruned)	5.97	14.27	20.73	23.35	–	5.95	19.86	19.62	18.13	21.13
	LSD (0.05)	NS	NS	2.447	2.534	–					
		2006 – 07									
	70% canopy pruning	9.40	25.31	44.23	47.54	–	7.88	25.97	32.98	30.19	33.46
	50% canopy pruning	7.62	21.91	39.42	43.66	–	7.17	23.73	30.60	27.88	30.04
	Control (unpruned)	4.39	9.26	14.47	19.63	–	3.82	15.69	15.79	15.00	17.78
	LSD (0.05)	NS	0.879	1.300	2.209	–					
		2005 – 06									
P	70% canopy pruning	1.37	4.34	7.45	9.17	–	1.21	4.89	5.96	6.31	12.87
	50% canopy pruning	1.29	4.25	7.27	8.98	–	1.15	4.58	5.66	6.01	12.26
	Control (unpruned)	0.81	1.94	3.28	3.99	–	0.81	2.49	3.21	3.46	6.91
	LSD (0.05)	NS	NS	0.410	0.412	–					
		2006 – 07									
	70% canopy pruning	1.30	3.47	7.02	8.18	–	1.02	3.22	5.38	5.79	11.52
	50% canopy pruning	1.05	3.02	6.25	7.51	–	0.92	2.94	4.99	5.35	10.73
	Control (unpruned)	0.60	1.26	2.31	3.36	–	0.51	1.94	2.58	2.87	6.13
	LSD (0.05)	NS	0.110	0.202	0.380	–					
		2005 – 06									
K	70% canopy pruning	10.12	29.79	37.28	42.36	–	11.32	45.73	54.41	55.79	64.02
	50% canopy pruning	9.56	29.14	36.37	41.46	–	10.83	42.80	51.66	53.10	60.82
	Control (unpruned)	6.14	13.47	16.58	18.55	–	7.64	23.26	29.35	30.55	36.43
	LSD (0.05)	NS	3.363	NS	NS	–					

Continue

		2006 – 07									
K	70% canopy pruning	9.50	23.77	35.14	37.79	–	9.51	30.06	49.08	51.04	57.80
	50% canopy pruning	7.72	20.52	31.30	34.78	–	8.58	27.47	45.53	47.13	51.97
	Control (unpruned)	4.52	8.73	11.57	15.61	–	4.81	18.12	23.57	25.30	30.71
	LSD (0.05)	NS	0.920	NS	NS	–					
Ca		2005 – 06									
	70% canopy pruning	3.26	10.22	17.45	22.02	–	1.14	4.56	5.50	5.77	6.62
	50% canopy pruning	3.08	10.00	17.01	21.56	–	1.09	4.27	5.22	5.49	6.29
	Control (unpruned)	1.97	4.62	7.77	9.65	–	0.77	2.32	2.97	3.17	3.77
	LSD (0.05)	0.0003	0.475	0.731	0.939	–					
		2006 – 07									
	70% canopy pruning	3.07	8.16	16.46	19.65	–	0.95	2.99	4.94	5.28	5.98
	50% canopy pruning	2.49	7.05	14.65	18.09	–	0.86	2.74	4.58	4.87	5.37
	Control (unpruned)	1.45	2.99	5.43	8.12	–	0.48	1.80	2.38	2.62	3.18
	LSD (0.05)	0.231	0.232	0.395	0.840	–					
Mg		2005 – 06									
	70% canopy pruning	1.91	5.96	9.76	12.76	–	0.66	2.63	3.14	3.26	3.72
	50% canopy pruning	1.81	5.83	9.55	12.49	–	0.63	2.46	2.98	3.10	3.53
	Control (unpruned)	1.15	2.69	4.33	5.59	–	0.45	1.34	1.69	1.79	2.12
	LSD (0.05)	0.216	0.276	0.370	0.546	–					
		2006 – 07									
	70% canopy pruning	1.80	4.76	9.18	11.38	–	0.55	1.72	2.81	2.97	3.35
	50% canopy pruning	1.46	4.11	8.19	10.48	–	0.50	1.57	2.61	2.75	3.01
	Control (unpruned)	0.85	1.75	3.00	4.70	–	0.28	1.04	1.36	1.48	1.78
	LSD (0.05)	0.135	0.136	0.239	0.487	–					

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively.
In case of mustard, March represents at harvest whereas in wheat, April represents at harvest

Table 4.35 Interaction effects of crop and pruning on nutrient accumulation in belowground biomass (kg ha^{-1}) of herbaceous layer at different months of the growing period during rabi season

Nutrient	Treatments	Mustard					Wheat				
		Dec.	Jan.	Feb.	March	April	Dec.	Jan.	Feb.	March	April
		2005 – 06									
N	70% canopy pruning	0.978	2.947	4.450	5.905	–	1.072	4.026	4.890	3.622	3.865
	50% canopy pruning	0.886	2.827	4.330	5.744	–	0.958	3.869	4.656	3.511	3.757
	Control (unpruned)	0.531	1.322	1.965	2.621	–	0.687	2.046	2.686	2.008	2.181
	LSD (0.05)	NS	NS	NS	0.506	–					
		2006 – 07									
	70% canopy pruning	0.902	2.359	4.538	5.312	–	0.816	2.675	4.489	3.110	3.500
	50% canopy pruning	0.718	2.015	4.013	4.865	–	0.737	2.444	4.118	2.865	3.132
	Control (unpruned)	0.416	0.849	1.474	2.186	–	0.379	1.612	2.148	1.514	1.849
	LSD (0.05)	NS	0.083	0.148	0.236	–					
		2005 – 06									
P	70% canopy pruning	0.112	0.338	0.529	0.705	–	0.100	0.330	0.407	0.472	0.498
	50% canopy pruning	0.102	0.324	0.515	0.686	–	0.089	0.318	0.388	0.457	0.484
	Control (unpruned)	0.061	0.152	0.234	0.313	–	0.064	0.168	0.224	0.261	0.281
	LSD (0.05)	NS	NS	0.056	0.064	-					
		2006 – 07									
	70% canopy pruning	0.104	0.270	0.540	0.635	–	0.076	0.220	0.374	0.405	0.451
	50% canopy pruning	0.082	0.231	0.477	0.581	–	0.069	0.201	0.343	0.373	0.404
	Control (unpruned)	0.048	0.097	0.175	0.261	–	0.035	0.132	0.179	0.197	0.238
	LSD (0.05)	NS	0.008	0.015	0.029	–					
		2005 – 06									
K	70% canopy pruning	0.921	2.796	4.281	5.742	–	0.504	1.825	2.053	2.375	1.903
	50% canopy pruning	0.834	2.683	4.166	5.586	–	0.450	1.753	1.954	2.302	1.850
	Control (unpruned)	0.500	1.254	1.891	2.549	–	0.323	0.927	1.128	1.316	1.074
	LSD (0.05)	NS	0.284	0.353	0.387	–					

Continue

K		2006 – 07									
	70% canopy pruning	0.850	2.238	4.366	5.166	–	0.383	1.212	1.884	2.039	1.723
	50% canopy pruning	0.676	1.912	3.861	4.731	–	0.346	1.108	1.729	1.879	1.542
	Control (unpruned)	0.392	0.805	1.418	2.126	–	0.178	0.730	0.902	0.993	0.910
	LSD (0.05)	0.073	0.062	0.108	0.222	–					
Ca		2005 – 06									
	70% canopy pruning	0.326	1.001	1.594	2.160	–	0.105	0.400	0.474	0.550	0.595
	50% canopy pruning	0.295	0.960	1.551	2.101	–	0.094	0.385	0.452	0.533	0.578
	Control (unpruned)	0.177	0.449	0.704	0.959	–	0.068	0.203	0.261	0.305	0.336
	LSD (0.05)	0.045	0.088	0.114	0.120	–					
		2006 – 07									
	70% canopy pruning	0.300	0.801	1.625	1.943	–	0.080	0.266	0.435	0.472	0.538
	50% canopy pruning	0.239	0.684	1.437	1.779	–	0.072	0.243	0.399	0.435	0.482
	Control (unpruned)	0.139	0.288	0.528	0.800	–	0.037	0.160	0.208	0.230	0.285
	LSD (0.05)	0.022	0.021	0.038	0.082	–					
Mg		2005 – 06									
	70% canopy pruning	0.190	0.586	0.922	1.244	–	0.061	0.230	0.269	0.301	0.323
	50% canopy pruning	0.172	0.562	0.897	1.211	–	0.055	0.221	0.256	0.292	0.314
	Control (unpruned)	0.103	0.263	0.407	0.552	–	0.039	0.117	0.148	0.167	0.182
	LSD (0.05)	0.026	0.052	0.066	0.068						
		2006 – 07									
	70% canopy pruning	0.176	0.469	0.940	1.119	–	0.047	0.153	0.247	0.258	0.293
	50% canopy pruning	0.140	0.401	0.831	1.025	–	0.042	0.140	0.227	0.238	0.262
	Control (unpruned)	0.081	0.169	0.305	0.461	–	0.022	0.092	0.118	0.126	0.155
	LSD (0.05)	0.013	0.012	0.022	0.047	–					

Dec., Jan, Feb., March and April represent 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively.
In case of mustard, March represents at harvest whereas in wheat, April represents at harvest

Table 4.36 Interaction effects of crop and pruning on nutrient accumulation in grain yield (kg ha^{-1}) of intercrops during rabi season

Treatments	Mustard					Wheat				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	2005 – 06									
70% canopy pruning	10.13	1.83	4.97	4.98	0.88	21.77	4.59	8.94	12.45	0.76
50% canopy pruning	9.80	1.77	4.81	4.82	0.85	20.82	4.39	8.55	11.91	0.72
Control (unpruned)	5.70	1.03	2.80	2.81	0.49	9.16	1.93	3.76	5.24	0.32
LSD (0.05)	0.63	0.12	0.29	0.34	0.03					
	2006 – 07									
70% canopy pruning	8.44	1.53	4.14	4.15	0.73	19.10	4.02	7.84	10.93	0.66
50% canopy pruning	7.18	1.30	3.52	3.53	0.62	17.04	3.59	7.00	9.75	0.59
Control (unpruned)	3.41	0.62	1.67	1.68	0.29	7.80	1.64	3.20	4.46	0.27
LSD (0.05)	2.16	0.02	0.91	1.21	NS					

Table 4.37 Growth and yield attributing characters of blackgram under different pruning regimes.

Character	Pruning regime			LSD (0.05)	Pure crop
	70% canopy pruning	50% canopy Pruning	Control (unpruned)		
	2005				
Plant population	4.63	4.17	1.67	0.92	5.41
Plant height (cm)	33.09	30.29	18.92	4.57	46.20
Branches plant $^{-1}$	3.50	3.00	1.23	0.86	5.56
Pods plant $^{-1}$	5.78	4.82	1.49	1.29	9.34
Grains pod $^{-1}$	5.64	5.19	2.39	0.33	6.14
Test Weight	32.28	31.52	22.85	4.10	35.14
Grain yield g 0.5 m $^{-2}$	4.63	4.28	2.02	0.22	9.78
	2006				
Plant population	3.57	3.04	1.17	0.67	4.59
Plant height (cm)	30.63	28.21	16.76	1.72	42.76
Branches plant $^{-1}$	3.14	2.69	1.18	0.76	5.15
Pods plant $^{-1}$	4.67	4.14	1.36	0.58	8.56
Grains pod $^{-1}$	3.67	2.91	1.34	0.18	4.80
Test Weight	30.59	28.60	20.59	2.58	32.42
Grain yield g 0.5 m $^{-2}$	2.28	2.02	1.01	0.10	5.85

Table 4.38 Growth and yield attributing characters of greengram under different pruning regimes

Character	Pruning regime			LSD (0.05)	Pure crop
	70% canopy pruning	50% canopy Pruning	Control (unpruned)		
	2005				
Plant population	5.13	4.89	2.83	0.42	6.04
Plant height cm)	46.13	43.19	22.82	2.12	50.38
Branches plant $^{-1}$	4.21	3.83	1.92	0.78	6.87
Pods plant $^{-1}$	6.00	5.84	2.06	1.43	10.37
Grains pod $^{-1}$	5.91	5.73	2.56	0.51	7.00
Test Weight	23.72	23.37	15.48	3.42	25.81
Grain yield g 0.5 m $^{-2}$	3.97	3.74	1.49	0.59	8.67
	2006				
Plant population	4.11	3.67	2.34	0.82	5.45
Plant height cm)	42.42	39.59	21.80	3.50	46.77
Branches plant $^{-1}$	3.63	3.00	1.53	0.72	5.30
Pods plant $^{-1}$	4.98	4.34	1.67	0.85	8.83
Grains pod $^{-1}$	4.34	3.98	1.96	0.71	5.63
Test Weight	22.36	21.16	15.14	1.90	25.81
Grain yield g 0.5 m $^{-2}$	2.63	2.19	1.06	0.44	6.39

Table 4.39 Grain yield (kg ha^{-1}) of intercrops under different pruning regimes during kharif season

Treatment	Kharif crop			
	Blackgram		Greengram	
	2005	2006	2005	2006
70% canopy pruning	92.63	45.67	79.33 (89.25)	52.53 (59.10)
50% canopy pruning	85.54	40.40	74.77 (84.12)	43.80 (49.23)
Control (unpruned)	40.45	20.20	29.84 33.57)	21.15 (23.79)
LSD (0.05)	5.68	2.06	14.81	8.81
Pure crop (without tree)	195.62	117.07	173.33 (195.00)	127.80 (143.78)

Selling price of blackgram and greengram was Rs. 16 and.18 kg $^{-1}$, respectively
Figures in parentheses are grain yield equivalent to blackgram

Table 4.40 Growth and yield attributing characters of mustard under different pruning regimes

Character	Pruning regime			LSD (0.05)	Pure crop
	70% canopy pruning	50% canopy Pruning	Control (unpruned)		
	2005 – 06				
Plant population	4.00	3.50	1.70	1.04	5.34
Plant height (cm)	145.99	139.70	117.01	3.24	156.22
Branches plant $^{-1}$	5.21	4.54	2.68	0.69	5.90
Siliquae plant $^{-1}$	191.71	184.77	94.70	9.18	271.33
Siliquae length (cm)	5.55	5.28	4.13	0.07	6.51
Seeds siliquae $^{-1}$	13.25	12.91	10.07	0.17	15.35
Test Weight	3.74	3.58	1.96	0.13	4.24
Grain yield g 0.5 m $^{-2}$	16.22	15.76	9.34	0.08	45.61
	2006 – 07				
Plant population	3.64	3.18	1.47	0.98	4.46
Plant height (cm)	139.92	133.38	106.07	7.87	149.64
Branches plant $^{-1}$	4.50	4.16	2.11	0.57	5.00
Siliquae plant $^{-1}$	173.74	158.04	79.19	21.37	246.71
Siliquae length (cm)	5.18	5.00	3.60	0.47	6.27
Seeds siliquae $^{-1}$	12.57	11.97	8.67	0.50	14.76
Test Weight	3.20	3.04	1.61	2.24	3.95
Grain yield g 0.5 m $^{-2}$	13.56	11.54	5.48	0.43	35.65

significant ($P \leq 0.05$) due to pruning regimes and values of growth and yield attributing characters were highest in 70% canopy pruning followed by 50% canopy pruning and control (unpruned). In pure crop (without tree), growth performance and yield attributing characters were better than agrisilviculture system.

Grain yield of both the crops was higher in 2005 – 06 than 2006 – 07 (Table 4.42). Among the pruning regimes, grain yield of both the crops was significantly ($P \leq 0.05$) higher (on an average 298.5 and 1092.6 kg ha^{-1} in mustard and wheat, respectively) in 70% canopy pruning than 50% canopy pruning and control (unpruned) during both the years. After estimating the mustard yield equivalent to wheat, it is very clear from the data, that wheat gave 2 times higher yield than mustard in all the pruning regimes. In pure crop (without tree), grain yield of both the crops was recorded 125–250% higher than agrisilviculture system.

4.15 Soil microbial biomass carbon and nitrogen

4.15.1 Soil microbial biomass carbon

Variation in soil microbial biomass carbon (C_{mic}) with crop sequences and pruning regimes is shown in Table 4.43. Soil C_{mic} was higher before sowing of kharif crop as compared to after harvesting of rabi crop in both the years. Before sowing of kharif crop, soil C_{mic} did not vary significantly due to crop sequences but there was significant ($P \leq 0.05$) variation in soil C_{mic} after harvesting of rabi crop. Soil C_{mic} was higher in blackgram – mustard crop sequence (701.56 – 833.71 µg g^{-1} soil) than greengram – wheat crop sequences. Among the pruning regimes, soil C_{mic} was significantly highest in 70% canopy pruning followed by 50% canopy pruning and control (unpruned). In 70% canopy pruning, soil C_{mic} was 3 and 8% higher than 50% canopy pruning and control (unpruned), respectively. In agrisilviculture system, soil C_{mic} was about 33% higher than pure crop (without tree).

4.15.2 Soil microbial biomass nitrogen

The result and trend in soil microbial nitrogen (N_{mic}) was similar to soil microbial carbon (Table 4.44). Soil N_{mic} did not exhibit significant variation due to crop sequence however, varied significantly ($P \leq 0.05$) due to the pruning. Among the pruning regimes, soil N_{mic} was higher in 70% canopy pruning (88.08 – 102.72 µg g^{-1} soil) than 50% canopy pruning and control (unpruned). In agrisilviculture system, soil N_{mic} was about 27% higher than pure crop (without tree).

Table 4.41 Growth and yield attributing characters of wheat under different pruning regimes

Character	Pruning regime			LSD (0.05)	Pure crop
	70% Canopy pruning	50% canopy Pruning	Control (unpruned)		
	2005 – 06				
Plant population	9.96	8.50	5.21	2.56	12.37
Plant height (cm)	84.91	81.63	66.45	6.53	94.53
Effective tillers plant $^{-1}$	4.57	4.10	2.25	1.00	6.50
Ear length (cm)	6.84	5.60	3.41	0.87	8.76
Grains ear $^{-1}$	40.08	37.70	23.66	4.79	58.94
Test Weight	39.11	37.54	27.95	0.78	44.36
Grain yield g 0.5 m $^{-2}$	59.03	55.79	24.95	5.16	103.72
	2006 – 07				
Plant population	8.96	7.95	4.54	1.46	10.35
Plant height (cm)	81.33	79.76	56.92	4.78	90.90
Effective tillers plant $^{-1}$	4.00	3.36	1.67	0.75	6.00
Ear length (cm)	6.07	5.58	3.00	1.10	8.58
Grains ear $^{-1}$	39.33	37.20	21.98	3.83	54.00
Test Weight	38.61	37.05	24.19	9.09	41.50
Grain yield g 0.5 m $^{-2}$	51.06	45.57	20.85	4.49	97.54

Table 4.42 Grain yield (kg ha $^{-1}$) of intercrops under different pruning regimes during rabi season

Treatment	Rabi crop			
	Mustard		Wheat	
	2005 – 06	2006 – 07	2005 – 06	2006 – 07
70% canopy pruning	325.74 (651.48)	271.27 (542.54)	1163.96	1021.20
50% canopy pruning	315.10 (630.20)	230.87 (461.74)	1113.35	911.40
Control (unpruned)	183.40 (366.80)	109.53 (219.06)	490.10	417.00
LSD (0.05)	24.33	44.84	41.22	181.84
Pure crop (without tree)	912.22 (1824.44)	712.93 (1425.86)	2074.30	1950.73

Selling price of wheat and mustard was Rs. 9 and 18 kg^{-1}, respectively
Figures in parentheses are grain yield equivalent to wheat

4.15.3 C_{mic}-to-N_{mic} ratio

C_{mic}-to-N_{mic} ratio was higher before sowing of kharif crop as compared to after harvesting of rabi crop (Table 4.45). Crop sequence did not affect C_{mic}-to-N_{mic} ratio significantly but it was slightly higher in blackgram – mustard crop sequence as compared to greengram – wheat. The effect of pruning on C_{mic}-to-N_{mic} ratio was also non significant. However, this ratio varied among the pruning regimes and was higher in control (unpruned) than 50 and 70% canopy pruning. In pure crop (without tree), C_{mic}-to-N_{mic} ratio was lower than agrisilviculture system.

4.16 Changes in physico-chemical properties of the soil

Changes in physico-chemical properties of the soil during study period are shown in Table 4.46. The results reveal that physico-chemical properties of the soil were better in upper 0–15 cm soil layer than lower 15–30 cm. There was slight decrease in pH and improvement in organic carbon, EC, available N, P and K in comparison to state before experimentation. The effect of crop sequences on physico-chemical properties of soil was non significant however values were slightly higher in blackgram – mustard crop sequence as compared to greengram – wheat.

Pruning had resulted in significant ($P \leq 0.05$) effects on physico-chemical properties of the soil. The soil EC and organic carbon were higher in 70% canopy pruning than 50% canopy pruning and control (unpruned) whereas available N, P and K were higher in control (unpruned) followed by 50 and 70% canopy pruning. However, there was no clear trend in the soil pH. In pure tree (without crop) soil pH, EC and OC was higher than agrisilviculture system but lower than pure crop (without tree). However, available N and K were lower than agrisilviculture system but higher than pure crop (without tree). Available P was highest in agrisilviculture system followed by pure crop (without tree) and pure tree (without crop).

Table 4.43 Microbial biomass carbon (μg g^{-1} soil) under *A. procera* based agrisilviculture system (before kharif and after rabi cropping)

Treatment	2005 – 06		2006 – 07	
	Kharif	Rabi	Kharif	Rabi
Crop sequence				
Blackgram – mustard	833.71	701.56	829.96	710.60
Greengram – wheat	828.29	696.61	827.57	707.82
LSD (0.05)	NS	2.61	NS	1.77
Pruning regime				
70% canopy pruning	862.35	726.43	854.28	731.22
50% canopy pruning	835.38	704.49	833.44	708.55
Control (unpruned)	795.41	666.35	798.58	687.86
LSD (0.05)	5.94	5.39	6.47	3.60
Pure crop (without tree)	600.27	534.62	620.68	542.43

Table 4.44 Microbial biomass nitrogen (μg g^{-1} soil) under *A. procera* based agrisilviculture system (before kharif and after rabi cropping)

Treatment	2005 – 06		2006 – 07	
	Kharif	Rabi	Kharif	Rabi
Crop sequence				
Blackgram – mustard	98.76	84.07	97.98	85.11
Greengram – wheat	98.29	83.65	97.80	84.86
LSD (0.05)	NS	NS	NS	NS
Pruning regime				
70% canopy pruning	102.72	87.97	101.28	88.08
50% canopy pruning	99.09	84.81	98.70	84.97
Control (unpruned)	93.77	78.81	93.70	81.90
LSD (0.05)	2.25	1.93	1.55	1.16
Pure crop (without tree)	76.47	66.00	77.25	68.19

Table 445 C_{mic}–to–N_{mic} ratio in soil under *A. procera* based agrisilviculture system (before kharif and after rabi cropping)

Treatment	2005 – 06		2006 – 07	
	Kharif	Rabi	Kharif	Rabi
Crop sequence				
Blackgram – mustard	8.45	8.35	8.47	8.35
Greengram – wheat	8.43	8.33	8.46	8.34
LSD (0.05)	NS	NS	NS	NS
Pruning regime				
70% canopy pruning	8.40	8.26	8.43	8.30
50% canopy pruning	8.43	8.31	8.44	8.34
Control (unpruned)	8.48	8.46	8.52	8.40
LSD (0.05)	NS	NS	NS	NS
Pure crop (without tree)	7.85	8.10	8.04	7.96

Table 4.46 Changes in physico – chemical properties of the soil under *A. procera* based agrisilviculture system during the study period.

Treatment	Initial						End of the study					
	pH	EC	OC	N	P	K	pH	EC	OC	N	P	K
Crop sequence						**0 – 15 cm soil depth**						
Blackgram – mustard	6.51	0.070	0.54	181.88	17.77	140.18	6.49	0.073	0.63	194.47	18.44	177.64
Greengram – wheat	6.50	0.071	0.53	180.30	17.03	139.80	6.48	0.072	0.61	193.40	18.12	176.76
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pruning regimes												
70% canopy pruning	6.51	0.072	0.56	178.34	16.33	138.97	6.50	0.074	0.65	191.04	17.09	172.54
50% canopy pruning	6.52	0.071	0.55	180.81	17.37	140.11	6.49	0.073	0.63	193.31	18.57	174.22
Control (unpruned)	6.49	0.069	0.51	184.12	18.50	140.90	6.47	0.071	0.58	197.46	19.18	184.85
LSD (0.05)	0.003	0.001	0.02	1.17	0.38	0.56	0.003	0.0004	0.02	1.61	0.54	2.21
Pure tree (without crop)	6.56	0.074	0.59	166.4	10.3	138.6	6.54	0.073	0.61	179.5	11.8	177.5
Pure crop (without tree)	6.61	0.060	0.50	160.1	12.4	133.4	6.59	0.061	0.51	167.1	12.9	169.2
Crop sequence						**15 – 30 cm soil depth**						
Blackgram – mustard	6.57	0.066	0.46	167.42	14.42	128.97	6.54	0.065	0.47	179.11	14.89	159.15
Greengram – wheat	6.57	0.067	0.45	166.39	14.07	128.11	6.54	0.065	0.46	178.10	14.66	158.33
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pruning regimes												
70% canopy pruning	6.57	0.068	0.56	163.97	13.32	126.62	6.56	0.067	0.49	175.28	13.98	156.04
50% canopy pruning	6.54	0.067	0.55	166.72	14.27	128.79	6.54	0.065	0.47	178.85	14.74	157.12
Control (unpruned)	6.60	0.065	0.51	170.02	15.14	130.21	6.52	0.063	0.43	181.68	15.60	163.07
LSD (0.05)	0.01	0.001	0.01	1.68	0.65	0.55	0.01	0.0004	0.01	0.86	0.31	0.93
Pure tree (without crop)	6.62	0.070	0.49	160.2	9.3	121.6	6.59	0.068	0.52	168.1	10.1	154.6
Pure crop (without tree)	6.64	0.63	0.39	155.7	10.5	125.2	6.61	0.062	0.40	156.3	11.1	136.8

Note: Units of physico-chemical properties are: EC dS m^{-1}, OC g kg^{-1} soil, available N, P and K kg ha^{-1}

Discussion

5. DISCUSSION

Agrisilviculture is an agroforestry system in which trees and annual food crops are included together that enhances productivity and ensures sustainability besides environmental benefit. In agrisilviculture, management of tree component requires an understanding of various factors that influence the growth of crops along with particular tree species. Therefore, the system requires appropriate silvicultural and agronomic management to get desired produce on a sustained basis for a long period. Normally in agroforestry, trees are managed through pruning of side branches which alter the functional balance of the tree and affects the growth and biomass yield of tree because growth of a tree is powered by the supply of assimilates that are chiefly produced by the leaves. Biomass production is directly correlated with the amount and intensity of canopy pruning. The results obtained from this experiment demonstrate that 70% canopy pruned tree accumulated less biomass, carbon and nutrients than unpruned trees but at the same time trees in 70% canopy pruning have minimum competition with crops and gave higher biomass of herbaceous layer than unpruned trees. The relative finding of the present experiment are discussed hereunder with appropriate citations.

5.1 Tree growth

The growth of *Albizia procera* (dbh and height) increased progressively with age and the annual increment in dbh and height was 2.7 cm and 1.5 m, respectively which was stable at 5.0, 6.0 and 7.0 years of age. Tree growth was comparatively higher in blackgram – mustard than greengram – wheat crop sequence but differences in tree height were significant. Higher tree growth in blackgram – mustard crop sequence was probably due to the fact that the same plot was utilized for soybean – wheat crop sequence upto 4 years before this study. Trees with this sequence benefited from higher doses of fertilizer, irrigation and other cultural practices which resulted in higher tree growth. After initiating this study, the soybean – wheat crop sequence was replaced by the blackgram – mustard crop sequence, which needs less fertilizer and irrigation. This was the reason for narrow down the difference in tree growth between blackgram – mustard and greengram – wheat crop sequence after initiation of this study.

It was well demonstrated in this experiment that pruning influences the growth response over unpruned tree. Tree growth (dbh and height) in 70% canopy pruning was lowest followed by 50% canopy pruning and control (unpruned). It has generally been found

that the impact of pruning on tree growth increases with the amount of the pruning (Luckhoff, 1967; Fujimori and Waseda, 1972; Sutton and Crowe, 1975; Takeuchi and Hatiya, 1977; Karani, 1978; Dakin, 1982, Pinkard and Beadle, 1998; Pires *et al.*, 2002; Pinkard *et al.*, 2004; Chandrashekara, 2007). Because heavy pruning leads to a greater removal of leaf area than light pruning, and more strongly reduces the overall carbohydrate production of a tree. In pruning not only the productive leaves are removed, but also some unproductive wood. This implies that pruning reduces both the production and the consumption of the carbohydrates, which affect the tree growth. Overall, tree growth was better in the agrisilviculture system than pure tree (without crop), probably due to the fact that trees also benefited from irrigation, fertilizer and tillage operations given to the crop under agrisilviculture. Similar results were also obtained by Cout and Gomez, 1995 with eucalyptus seedlings in which fertilizer and weeding given to the agricultural crop also benefited the growth of eucalyptus seedlings when compared to the eucalyptus monoculture. In another study, tree height and dbh of intercropped *Paraserianthes falcataria* tree at two years age were 33 and 21% higher, respectively than sole tree (Nissen *et al.*, 2001). In a similar study, Chifflot *et al.* (2006) also reported the growth of wild cherry (*Prunus aivium*) and hybrid walnut (*Juglans nigra* L. × *J. regia* L.) improved in association with crops.

5.2 Tree biomass

Standing biomass of trees was estimated by using the dbh based nonlinear regression equations [$Y = a(dbh)^b$]. The allometric equation obtained by nonlinear regression represented well the correlation between the breast height diameter and biomass, as reported by Clough and Scott (1989) and Niklas (1994). This is also in agreement with Schoman and Boden (1981), who hypothesized that when the trees are sampled from the same locality and for the same species under uniform conditions, the relationship between dbh and height is very close and inclusion of tree height does not contribute significantly to the regression. Based on the monoculture plantations, dbh based models were the best predictor for biomass estimation (Bargali *et al.*, 1992; Lodhiyal and Lodhiyal, 1997; Salis *et al.*, 2006).

The standing biomass of *A. procera* increased with the tree age but increment in biomass accumulation was almost stable at different age of the tree. Several other studies have also reported the similar results with age sequence of tree stand (Sprugel, 1984; Ruark and Bockheim, 1988; Wang *et al.*, 1996, Swamy *et al.*, 2003). The contribution of

different components for total biomass was in the order of branch > root > main bole > foliage. The influence of crop sequences on biomass production was not very much obvious but pruning treatments had great influence on biomass production and distribution patterns in different components of the tree. Total biomass was highest in control (unpruned) followed by 50 and 70% canopy pruning (Table 4.3). The results clearly show that pruning reduced biomass production and this reduction has positive relation with amount of pruning. The trees with 70% canopy pruning tended to produce less biomass than 50% canopy pruning. Similar results have been reported by Lehtpere (1957), Møller (1960), Uotila Mustonen (1994) and Zeng (2003). Most likely, this reduction is due to the diminished overall photosynthesis of pruned trees, because pruning of branches leads to a decrease in remaining leaf area and to a decrease in the number of buds from which new branches and leaves can be produced. Due to decreased assimilate production, the growth of pruned tree is generally reduced (Pinkad and Beedle, 1998; Pinkard *et al.,* 1999; Bandara *et al.,* 1999).

Component wise biomass allocation pattern was also different in all the pruning regimes. In control (unpruned), branch biomass represented about 40–41% and main bole 15–16% of the total tree biomass whereas in 50% canopy pruning, branch represented 31–33% and main bole 24–26% of the total tree biomass. However, it was just opposite in 70% canopy pruning, where main bole represented 38–39% and branch 17– 20% of the total tree biomass. This was due to the fact that trees are commonly pruned by removing leaves and branches from lower part of the crown which changes the stem shape to a more cylindrical form and increases the clear bole length, resulting in more biomass allocation in bole than other tree components. Shepherd (1986) and Muhairwe (1994) have hypothesized that pruning change stem shape to a more cylindrical form. In tamarack (*Larix laricina* (du Roi) K. Koch), Larson (1965) reported more cylindrical stem shape by reducing crown size by pruning.

5.3 Litter biomass

Litter fall production was almost similar in both the crop sequences but pruning treatments significantly affected the rates of litter fall production (Table 4.4). Litter fall production was recorded highest in control (unpruned) followed by 50 and 70% canopy pruning. Over all, the litter yield during May, June and July months was less; August, September and October months was moderate and during November, December, January, February and March months was highest during both the years (Fig. 4). In

pruning branches and leaves are removed from the lower part of the crown, resulting in diminished leaf mass ratio which affects the rate of litter fall production. The results were in confirmity with George and Kumar (1998), they also reported that lopping/pruning of MPTs affects the rate of litter fall production.

5.4 Fine and small root biomass

Fine root (0–2 mm) and small root (2–5 mm) biomass of *A. procera* varied with season and variation in root biomass might be due to the edaphic environment for example, proper soil moisture, soil temperature, soil strength, decomposition of organic material and rate of root turnover. Fine and small root biomass was higher during kharif cropping (rainy season) as compared to rabi cropping (winter season) and increased with tree age (Table 4.5 and 4.7). The higher root biomass might be due to the new flushes that start with the onset of rainfall and secondly during rainy season edaphic environment favours the higher root formation. In *Cryptomeria japonica,* Konopka *et al.* (2006) reported increased fine root biomass until late summer (August) and then declined. These results are also in agreement with Dhyani *et al.* (2000), they reported that fine root (0–2 mm) and coarse root (2–5 mm) biomass of albizia, alder, cherry and mandarin was higher in rainy season than winter season. In a similar study, Tufekcioglu *et al.* (1999) also observed that fine root biomass from August to October was maximum in a multispecies in riparian buffer. However, an annual peak in fine root biomass in spring or early summer was reported for trees by Farish (1991) and Joslin and Handerson (1987). This type of seasonal variation in root biomass could be attributed to changes in edaphic environment such as soil moisture, soil temperature, litter accumulation and root turnover (Hook *et al.,* 1994; Sundarapandian *et al.,* 1996). The distribution of fine and small roots according to soil depth during both the seasons clearly indicate that within the investigated soil profile (0–60 cm soil depth) most of the roots (>77%) were in the top 30 cm soil profile. The higher root concentration in upper soil layer might be due to the better nutrient and moisture availability, which attract the roots to move on upper surface. Similar results have been reported in a number of other studies which confirm that in most of the multipurpose trees, roots are in the top of the soil profile (Jonsson *et al.,* 1988; Ruhigwa *et al.,* 1992; Toky and Bisht, 1992; Torquebiau and Kwesiga, 1996; Tufekcioglu *et al.,* 1999; Peter and Lehmann, 2000; Dhyani *et al.,* 2000; Konopka *et al.,* 2006). This rotting pattern is due to better recharge of water and higher levels of nutrients in the upper soil (Pandey *et al.,* 2000; Hoad *et al.,* 2001; Bayala *et al.,* 2004)

Pruning significantly affected the fine and small root biomass and among the pruning regimes, fine and small root biomass was highest in control (unpruned) and lowest in 70% canopy pruning. The lowest root biomass in 70% canopy pruning might be due to the removal of large amount of branches and green leaves that reduces the assimilation rate and consequently influences the root system. As in the present study a reduction in root density attributed to less root biomass accumulation. This was confirmed with findings of Fownes and Anderson (1991) and Peter and Lehmann (2000), they reported that pruning reduces the root density in *Sesbania sesban, Leucaena leucocephala* and *Acacia saligna.* In addition, Schroth and Zech (1995) reported lower root length densities when *Gliricidia sepium* (Jacq.) Walp. was pruned. Reduction in root length density in pruned plots of *Prosopis juliflora* in a semi-arid region of north-east Nigeria has been also reported by Jones *et al.* (1998). In pure tree (unpruned), cultural practices are not applied that kept the upper soil layer undisturbed and whatever roots are presented on the upper soil surface remain as such without any damage. This resulted in higher concentration of roots. Contrary to this, in the agrisilvicultural system tillage practices are used to grow intercrops that destroy fine and small roots in the top soil. Schroth (1995) and Ram Newaj *et al.* (2001) also mentioned that soil tillage may be used to destroy tree roots in the topsoil before sowing of crops to reduce competition between tree and crop.

5.5 Biomass of herbaceous layer during kharif and rabi season

Biomass of herbaceous layer increased with the advancement of crop growth. Biomass accumulation varied during the study period (Table 4.8 and 4.10). This might be due to the variation in amount of rainfall and its distribution and increasing age of the tree. The continuous decrease in biomass of the herbaceous layer with increasing tree age resulted due to increasing demand of the trees for available growth resources for which they competes with the cops. Lodhiyal *et al.* (1995) stated in a *Populus deltoids* based study that biomass of herbaceous species declined with increased stand age. In a similar study, Das and Chaturvedi (2005) reported that total biological yields in maize-wheat-turmeric and pigeonpea-turmeric cropping pattern decreased with an increase in plantation age. The growth and development of kharif crops (blackgram and greengram) was very poor due to severe drought. Crop received little amount of rainfall with several drought spells which badly affected the growth and development of the crop. However in kharif, greengram accumulated higher biomass than blackgram whereas in rabi, wheat

accumulated higher biomass than mustard. The difference in biomass accumulation between the crops was due to their different nature.

Biomass of herbaceous layer was highest in 70% canopy pruning and lowest in control (unpruned). The higher biomass accumulation in herbaceous layer with pruned tree might be due to the canopy pruning that facilitates more light to understorey vegetation and alleviates shading of understorey crop. The present results are in confirmity with the studies carried out on pruning in agrisilviculture by Osman *et al.* (1998) and Droppelmann and Berliner (2003), they reported that crop plants (sorghum or cowpea) grown with the pruned trees attained higher dry matter than those with the unpruned trees. Similar results have also been reported by several other workers (Miah *et al.*, 1997; Okun Omo *et al.*, 2001; Bayala *et al.*, 2002). The work on alley cropping done by several workers (Viswanath *et al.*, 1997; Dugma *et al.*, 1988; Kang *et al.*, 1990) has also proven pruning of hedgerows as useful practice for obtaining good yields of crops.

In pure crop (without tree), biomass of herbaceous layer was comparatively higher than the agrisilviculture system because crops under pure system did not have any competition for available growth resources with the tree component as in the agrisilviculture system.

5.6 Carbon accumulation in tree biomass

Carbon concentration varied considerably between the tree components and was highest in branch, followed by main bole, root and foliage (Appendix – 19). The carbon accumulation followed the temporal pattern of biomass accumulation and increased with tree age (Table 4.12). The carbon accumulation was 12.28 to 12.39 t C ha^{-1} at 5 years age and increased upto 23.87 to 24.56 t ha^{-1} at 7 years of the age. The difference in carbon accumulation due to the crop sequence was very less, because the growth of trees with both the crop sequences was almost similar. Mean annual increment in carbon accumulation was 2.96 t C ha^{-1} $year^{-1}$, which was low as compared to carbon accumulation estimated in plantations of tropical Asia. The studies of carbon accumulation in other tree species indicates that the net carbon accretion in tropical plantations of Asia ranged from 6.4 to 10 t ha^{-1} $year^{-1}$ (Nilsson and Schopfhauser, 1995; Haripriya, 2002). Carbon storage depends on species, density, site quality, climate and silvicultural management practices adopted in the plantations. Mean annual carbon accretion in *A. procera* was also less than that reported by Swamy *et al.* (2003) for

Gmelina arborea (4.31 t C ha^{-1} $year^{-1}$) grown on red lateritic soils. However, our estimates are comparable with the carbon storage pattern in silvipostoral systems on a sodic soil as reported by Kaur *et al.* (2002). The total carbon storage in *Prosopis juliflora*, *Dalbbergia sissoo* and *Acacia nilotica* with grasses (*Desmostachya bipinnata* and *Sporobolus marginatus*) ranged from 4.95 to 14.80 t h^{-1}. In general, among the tree components, branch accounted for maximum carbon followed by root, main bole and foliage irrespective of pruning regimes.

Among the pruning regimes, the highest carbon accumulation was in control (unpruned) followed by 50 and 70% canopy pruning. The lowest carbon accumulation in 70% canopy pruning was due to the removal of large portion of branches and foliage that affects the biomass accumulation. The study of Kang *et al.* (2006) clearly indicates that carbon storage is directly related to the corresponding amount of biomass. Component wise carbon accumulation was in the order of branch > root > main bole > foliage in control (unpruned) and 50% canopy pruning whereas main bole > root > branch > foliage in 70% canopy pruning. In pure tree (without crop), carbon accumulation was less than trees in the agrisilviculture system because trees in the agrisilviculture system are benefited from fertilizer, irrigation and other cultural practices given to the intercrops.

5.7 Carbon in litter biomass

The amount of carbon return on floor through litter fall was almost similar in both the crop sequences but was significantly affected by pruning regimes (Table 4.13). Carbon return on ground was recorded highest in control (unpruned) followed by 50 and 70% canopy pruning. This is related to the higher litter fall production in control (unpruned) than 50 and 70% canopy pruning. During pruning, branches and leaves are removed from the crown resulting in diminished leaf mass ratio that affects the rate of litter fall production and simultaneously carbon return on the ground.

5.8 Carbon accumulation in fine and small root biomass

Carbon accumulation in fine and small root biomass was higher during kharif cropping as compared to rabi cropping and increased with tree age (Table 4.14 and 4.16). This was due to the higher biomass of fine and small roots during kharif cropping as compared to rabi cropping because carbon accumulation is directly related to the corresponding amount of biomass (Kang *et al.*, 2006). As per the soil depth, carbon accumulation in

fine and small root biomass was highest in upper 0–30 cm soil layer and it contributed about 77% of the total carbon accumulation at 0–60 cm soil depth.

Carbon accumulation in fine and small root biomass of the tree was significantly higher in blackgram – mustard than greengram – wheat crop sequence. The higher growth of trees in this crop sequence contributed to the higher biomass and carbon in fine and small roots of the trees. Among the pruning regimes, carbon accumulation in fine and small roots was significantly highest in control (unpruned) followed by 50 and 70% canopy pruning because unpruned trees contributed higher biomass than pruned trees. In pure tree (without crop), carbon accumulation in fine and small root biomass was higher than trees in the agrisilviculture system.

5.9 Carbon accumulation in herbaceous biomass during kharif and rabi season

Carbon accumulation increased simultaneously with the increasing biomass of the herbaceous layer at different stages of the crop growth (Table 4.17 and 4.19). Generally, carbon accumulation in different components of herbaceous layer was in the order of crop > weed > root > floor litter. Carbon content (%) in grain was in order of mustard > greengram > blackgram > wheat whereas carbon accumulation was in the order of wheat > mustard > blackgram > greengram because grain production in wheat was higher than other crops. Greengram accumulated significantly higher carbon than blackgram whereas wheat accumulated higher carbon than mustard. The differences in carbon accumulation between the crops were due to different nature and biomass accumulation pattern of the crops.

Among the pruning regimes, crops grown with 70% canopy pruned trees accumulated significantly higher carbon than those grown with 50% canopy pruned trees and unpruned trees. Trees in 70% canopy pruning exerted minimum competition for light, moisture and nutrients that results in higher herbaceous biomass yields than control (unpruned) and 50% canopy pruning. In pure crop (without tree), carbon accumulation in herbaceous biomass was comparatively higher than that in the agrisilviculture system. In pure system, crops did not have any competition for growth resources that results in higher biomass production and simultaneously carbon accumulation.

5.10 Nutrient accumulation in tree biomass

The nutrient concentration varied in different tree components and highest concentration was observed in leaves followed by root, branch and main bole (Appendix– 19). As per

the data of Wang *at al.* (1991), the order of nutrient concentration for different components of aboveground biomass was consistent in *Albizia procera.* The nutrient accumulation in tree increased with age because dry matter accumulation also increased with tree age. The total nutrient accumulation in tree biomass was in the order of N > Ca > K > Mg > P (Table 4.21). Nutrient accumulation in each component of tree depends on nutrient concentration and dry matter yield of a particular component. In general, nutrient accumulation was highest in root followed by foliage, branch and main bole.

Nutrient accumulation significantly varied due to the amount of pruning. It is well established fact that pruning affects the biomass productivity of a tree and nutrient accumulation/retention depends upon the amount of biomass accumulated by the tree. This was the reason for higher biomass as well as nutrient accumulation in unpruned trees as compared to 50 and 70% canopy pruning. The results of several studies (Uotila Mustonen, 1994; Pinkad and Beedle, 1998; Pinkard *et al.,* 1999; Bandara *et al.,* 1999; Zeng, 2003) have already been quoted while discussing the effect of pruning on biomass of tree. Nutrient accumulation in pure tree (without crop) was comparatively less than trees in the agrisilviculture system because trees in the agrisilviculture system has accumulated higher biomass than pure tree.

5.11Nutrients in litter biomass

The amount of nutrients in litter biomass was in the order of Ca > N > K > Mg > P. Nutrients in litter biomass were almost similar in both the crop sequences during 2005 – 06. However in 2006 – 07, nutrients were significantly higher in blackgram – mustard than greengram – wheat crop sequence (Table 4.22). The higher litter production in blackgram – mustard crop sequence attributed higher nutrient accumulation. Among the pruning regimes, nutrients in litter biomass were significantly higher in control (unpruned) than 50 and 70% canopy pruning because unpruned trees had more litter fall production than 50 and 70% canopy pruning. In pure tree (without crop), the amount of nutrients in litter biomass were less than trees in the agrisilviculture system. This was probably due to the better growth of trees in the agrisilviculture system in which trees were benefited from irrigation and fertilizer given to the crop.

5.12 Nutrient accumulation in fine and small root biomass

In fine and small root biomass, nutrient accumulation was in the order of N > Ca > K > P > Mg (Table 4.23 and 4.24). The nutrient concentration was higher in fine roots as

compared to small roots (Appendix – 19). Nutrient accumulation in fine and small root biomass was higher in kharif cropping as compared to rabi cropping, and increased with tree age. Among the crop sequences, trees in blackgram – mustard accumulated significantly higher nutrients in fine and small root biomass than greengram – wheat crop sequence. This might be due to the better growth of trees in blackgram – mustard crop sequence that gave higher fine and small root biomass.

Nutrient accumulation in fine and small root biomass varied significantly due to the pruning. Control (unpruned) accumulated highest nutrients whereas 70% canopy pruning accumulated lowest nutrients (N, P, K, Ca and Mg). The higher growth of trees in control (unpruned) contributed to the higher biomass and nutrient accumulation in fine and small roots of the trees. Pure tree (without crop) accumulated higher nutrients in fine and small root biomass than trees in the agrisilviculture system. This was due to the higher fine and small root biomass in pure tree because nutrient accumulation is directly related to the corresponding amount of biomass.

5.13 Nutrient accumulation in herbaceous biomass during kharif and rabi season

Nutrient accumulation in herbaceous biomass increased with the advancement of crop growth (Table 4.26, 4.27, 4.28, 431, 4.32 and 4.33), except N in wheat, which increases upto 2nd month after sowing and then slightly declined. Nutrient accumulation in herbaceous biomass (above and belowground biomass) was in the order of N > K> Ca > P > Mg. However, in grain it was in the order of N > Ca > K > P > Mg. Greengram accumulated higher nutrients than blackgram, except P and K whereas wheat accumulated higher nutrients than mustard, except K. This was mainly due to the differences in biomass accumulation.

Nutrient accumulation differed significantly among the pruning regimes. Over the entire growing season, 70% canopy pruning had higher nutrient accumulation than did 50% canopy pruning or control (unpruned). This was due to the higher biomass production in 70% canopy pruning. Interaction effects of crop and pruning on nutrient accumulation were also significant (Table 4.29, 4.30, 4.34 and 4.35). This was mainly due to the difference in biomass production and different nature of crops. In pure crop (without tree), nutrient accumulation in above and belowground biomass was higher than in the agrisilviculture system.

4.14 Growth, yield and yield attributing characters of intercrops

The growth, yield and yield attributing characters of intercrops (blackgram and greengram, mustard and wheat) were better during 2005 – 06 as compared to 2006 – 07 (Table 4.37, 4.38, 4.39, 4.40, 4.41 and 4.42). This was mainly due to the fact that crop received comparatively higher amount of rain (440.7 mm) during kharif, 2005 and subsequently it helped in the availability of irrigation water during rabi season. Although, annual rainfall was very less during both the years. The lower yield during 2006 – 07 may also be due to increasing growth of the trees which compete more for available growth resources. Many studies revealed that the level of effect on growth and yield of crop by tree component in tree-crop system under different level of stresses are caused by growth behaviour and age of tree (Ralhan *et al.,* 1992; Puri *et al.,* 1994; Schroth, 1999; Puri and Sharma, 2002).

The growth and yield attributing characters of crops varied significantly among pruning regimes and were recorded highest in 70% canopy pruning followed by 50% canopy pruning and control (unpruned). Light availability is the most important limiting factor for the performance of understorey annual crops particularly where upper storey perennial from a dense overstorey canopy (Miah *et al.,* 1995). Canopy pruning alleviated shading and facilitate penetration of light to the understorey crops. The benefits of pruning has been well recognized by several workers (Acciaresi *et al.,* 1994; Viswananth *et al.,* 1998; Osman *et al.,* 1998). Samsuzzaman *et al.* (2002) stated that shoot pruning had significant positive effect on the crop yield. In another study, Upadhyaya and Nema (2003) reported improved light penetration and significantly increased yield of wheat and paddy rice by pruning in *Acacia*-based agrisilviculture system. Similar results were also reported by Thakur and Singh (2002) in case of *Morus alba*, in which 75% canopy removal allowed more light transmission as compared to 0, 25 and 50% canopy removal. In pure crop (without tree), growth, yield and yield attributing characters were comparatively higher than agrisilviculture system because crops under pure system did not have any competition with tree component.

4.15 Soil microbial biomass C, N and C_{mic}-to-N_{mic} ratio

Microbial biomass plays a key role in the processes of soil organic matter dynamics and soil nutrient availability in the agricultural ecosystems. Soil management practices strongly affect the size of the microbial biomass, particularly the input of C substrates

(Brookes *et al.,* 1990). The build up of microbial biomass during organic matter decomposition and the biomass turn over vary in soils of different textures, land uses and with different amendments (Lynch and Panting, 1980; Van Veen *et al.,* 1987; Vanlauwe *et al.*, 1996; Upadhyaya *et al.*, 2003; Singh *et al.*, 2004).

Soil microbial C, N and C_{mic}-to-N_{mic} ratio was higher before sowing of kharif crop as compared to after harvesting of rabi crop (Table 4.43, 4.44 and 4.45). Seasonal changes in environmental conditions (rainfall, soil moisture and temperature) influenced microbial processes. Wardle (1992) attributed seasonal variation in microbial biomass due to seasonal variation in temperature and soil water, while Mazzarino *et al.* (1993) stated that seasonal changes of microbial biomass appeared to depend more on crop phenology, management practices (pesticides and fertilizer applications) and soil moisture. The highest amount of microbial biomass C and N before sowing of kharif crop was possibly due to a gap of about three months between harvesting of rabi crop and sowing of kharif crop. During this period, there was no loss and demand of nutrients. Mineralization products and nutrients that move upward through capillary action were mobilized in the microbial biomass.

Among pruning regimes, soil microbial C and N was significantly highest in 70% canopy pruning followed by 50% canopy pruning and control (unpruned). Significantly higher amounts of soil microbial biomass C and N under pruning treatment might be due to addition of varying quantity of organic matter inputs through pruned material, litter fall and fine roots as microbial C and N are positively correlated with soil organic matter. The availability of carbonaceous materials and substrates such as sugars, amino acids and organic acids to the soil from the decomposing pruned material, litter fall and roots are important for supplying energy for microbial populations (Bowen and Rovira, 1991). Similar observations were also made by Schnurer *et al.* (1985), Powlson *et al.* (1987), Roy and Singh (1994), Ruess and Seagle (1994), Goshal and Singh (1995), Singh and Singh (1995), Ros *et al.* (2003) and Yadav (2005) in which microbial C and N increased due to higher organic matter. In the present study Soil C_{mic}-to-N_{mic} ratio was recorded higher in control (unpruned) followed by 50 and 70% canopy pruning. The differences in C_{mic}-to-N_{mic} ratio indicate that composition of soil microflora was affected by pruning of trees. Changes in this ratio may affect the rate of mineralization (Hassink *et al.*, 1991), a wide C_{mic}-to-N_{mic} ratio indicates a high proportion of fungi compared to bacteria and actinomycetes (Cambell *et al.*, 1991), as the C_{mic}-to-N_{mic} ratio of fungal hyphae is in the

range of 7–12, whereas that of bacteria between 3 and 6 (Jenkinson, 1978; Anderson and Domsch, (1980). Although there is no empirical evidence from this study, it can only be presumed that control (unpruned), 50 and 70% canopy pruning may have supported the fungal and bacterial dominated food webs, respectively. Wider ratios under control (unpruned) might have led greater retention of microbial C and N.

In agrisilviculture system, soil microbial C and N was comparatively higher than pure crop (without tree) whereas soil C_{mic}-to-N_{mic} ratio was less than pure crop (without tree). Kaur *et al.* (2000) also reported low microbial biomass carbon in rice–berseem crops and increased in soils under tree plantations (*Acacia*, *Eucalyptus* and *Populus*) and agrisilvicultural systems.

5.16 Changes in physico-chemical properties of the soil

Physico-chemical properties of the soil were higher in upper 0 – 15 cm soil layer than lower 15–30 cm (Table 4.46). There was slight decrease in pH and improvement in organic carbon, EC, available N, P and K in comparison to state before experimentation. This might be due to the addition of tree litter, crop residues and root turnover. The present observation is in confirmity with Swamy *et al.* (2006), they also reported decrease in available N, P and K with soil depth in *Populus deltoides* based agrisilviculture system and significant increase after six years of planting.

There was a decrease in soil pH during the study period. This decline in pH could be due to litter fall, which on decomposition is known to produce weak acids (Mishra *et al.*, 1985; Hosur and Dasog, 1995). The several field studies (Gill and Abrol, 1991; Shukla and Mishra, 1993; Dagar *et al.*, 2001; Chaturvedi and Das, 2002; Ram Newaj *et al.*, 2007) made similar observations in which trees reduce the soil pH. Similarly improvement in electrical conductivity (EC) was due to enrichment of soilmin basic salts through addition and decomposition of litter fall. The increase in soil organic carbon in agrisilviculture system could be attributed to higher organic inputs in the form of litter fall and fine roots from the tree. Such tree based improvement in SOC was also reported by Jha *et al.* (2000), Jhorar and Singh (2000), Singh *et al.* (2000), Rai *et al.* (2001), Singh *et al.* (2004), Yadav (2005) and Ram Newaj *et al.* (2007).

The improvement in N, P and K content of soil might be due to the addition of these nutrients through litter fall and root decay. Tree induced increase in availability of N, P

and K in soil was also reported by Datta and Dhiman (2001), Singh *et al.* (2004), Yadav (2005), Swamy *et al.* (2006) and Ram Newaj *et al.* (2007).

Pruning had resulted in significant effects on physico-chemical properties of the soil. The soil EC and OC were higher in 70% canopy pruning followed by 50% canopy pruning and control (unpruned). However, there was no clear trend in the soil pH. The higher EC and OC in 70% canopy pruning were probably due to the higher decomposition rate of pruned material, litter fall and roots. In the present study, available N, P and K were higher in control (unpruned) compared to 50 and 70% canopy pruning. This might be due to more addition of nutrients through tree litter and root decaying and less removal of nutrients by intercrops.

The improvement in soil fertility was seen in agrisilviculture after two years of study as compared to pure cropping which indicates that growing of crop with tree helps in soil nutrient build up through addition of litter fall and root decaying.

Summary and conclusions

6. SUMMARY AND CONCLUSIONS

The results of present study entitled "Biomass, carbon and nitrogen dynamics as affected by different pruning regimes in *Albizia procera* based agrisilviculture system" have been described and discussed in the preceding chapters. The findings of the study are summarized and concluded in this chapter as follows:-

- The growth of *Albizia procera* (dbh and height) increased with tree age and increment in dbh and height was almost stable at 5.0, 6.0 and 7.0 years age. Tree growth was slightly higher in blackgram – mustard as compared to greengram – wheat crop sequence. Among the pruning regimes, tree growth was in the order of control (unpruned) > 50% canopy pruning > 70% canopy pruning. The growth of pure tree (without crop) was less than trees in the agrisilviculture system.

- Tree biomass increased with age with a mean annual increment of 6.30 t ha^{-1} $year^{-1}$. Allocation of biomass in different tree components was in the order of branch > root > main bole > foliage Tree biomass with blackgram – mustard crop sequence was comparatively higher than greengram – wheat crop sequence. Among the pruning regimes, unpruned trees had significantly higher biomass than 50 and 70% canopy pruned trees. Trees in the agrisilviculture system accumulated higher biomass than pure tree (without crop).

- Annual litter fall production of *Albizia procera* was almost similar in both the crop sequences but significantly varied among the pruning regimes. Litter fall production was recorded in the order of control (unpruned) > 50% canopy pruning > 70% canopy pruning. In pure tree (without crop) litter fall production was less than that of the agrisilviculture system.

- Fine root and small root biomass of *A. procera* was higher in kharif cropping as compared to rabi cropping. As per the soil depth, fine root biomass was highest at 0 – 15 cm whereas small root biomass was highest in 15 – 30 cm soil depth. Fine and small root biomass of trees was significantly higher in blackgram – mustard than greengram – wheat crop sequence. Among the pruning regimes, fine and small root biomass was highest in control (unpruned) and lowest in 70% canopy pruning. In pure tree (without

crop), fine and small root biomass was comparatively higher than agrisilviculture system.

- Biomass of herbaceous layer increased with the advancement of crop growth. The biomass of blackgram, greengram, wheat and mustard varied due to their different nature. Component wise biomass of herbaceous layer was in the order of crop > weed > root > floor litter. The crop grown with 70% canopy pruning had highest biomass and lowest with control (unpruned). The herbaceous biomass of pure crop (without tree) was comparatively higher than that of the agrisilviculture system, except weed biomass in rabi season.

- Carbon concentration varied considerably between the tree components and was in the order of branch > main bole > root > foliage. Carbon accumulation increased with tree age with a mean annual increment of 2.96 t C ha^{-1} $year^{-1}$. Component wise carbon accumulation was in the order of branch > root > main bole > foliage. Trees with blackgram – mustard accumulated slightly higher carbon than greengram – wheat crop sequence. Among the pruning regimes, control (unpruned) accumulated significantly highest carbon followed by 50 and 70% canopy pruning. In pure tree (without crop), carbon accumulation was less than that of the agrisilviculture system.

- The amount of carbon in litter biomass of *A. procera* was almost similar in both the crop sequences. However among the pruning regimes, it was significantly higher in control (unpruned) than 50 and 70% canopy pruning. In pure tree (unpruned), the amount of carbon in litter biomass was 21–24% less than trees in the agrisilviculture system.

- Carbon accumulation in fine and small root biomass of *A. procera* was higher during kharif cropping as compared to rabi cropping. Of the total carbon, fine and small roots at 0 – 30 cm soil layer contributed 77% and 30 – 60 cm soil layer contributed 33%. Fine and small roots of trees with blackgram – mustard accumulated significantly higher carbon than greengram – wheat crop sequence. Carbon accumulation in fine and small root biomass of unpruned trees was highest, whereas that of the 70% canopy pruned trees was lowest.

- Carbon accumulation in herbaceous layer followed the pattern of biomass accumulation. Component wise carbon accumulation was in the order of crop > weed > root > floor

litter. Among the pruning regimes, carbon accumulation was highest in 70% canopy pruning and lowest in control (unpruned). In pure crop (without tree), carbon accumulation was comparatively higher than that of the agrisilviculture system.

- The concentration of nutrients (N, P, K, Ca and Mg) among tree components was generally graded in the following order: leaves > fine root > coarse root > branch > main bole. Total nutrient storage in tree biomass was in the order of N > Ca > K > Mg > P. Trees with blackgram – mustard accumulated higher nutrients than greengram – wheat crop sequence. Among the pruning regimes, unpruned trees accumulated higher nutrients as it did in the case of biomass and carbon. Pure tree (without crop) accumulated less nutrients than that of the agrisilviculture system.
- The amount of nutrients in litter biomass of *A. procera* was in the order of Ca > N > K > Mg > P. Nutrients in litter biomass were almost similar in both the crop sequences. However, nutrients were significantly highest in control (unpruned) and lowest in 70% canopy pruning. In pure tree (without crop), the amount of nutrients in litter biomass was less than that of the agrisilviculture system.
- The pattern of nutrient accumulation in fine and small root biomass of tree was similar to the biomass and carbon content. Nutrients were in the order of N > Ca > K > P > Mg. Among the pruning regimes, nutrient accumulation was in the order: control (unpruned) > 50% canopy pruning > 70% canopy pruning. Pure tree (without crop) accumulated higher nutrients in fine and small root biomass than trees in the agrisilviculture system.
- Nutrient accumulation in herbaceous biomass was in the order of N > K> Ca > P > Mg and increased with the advancement of crop growth, except N in wheat, which increases upto 60 DAS and then slightly declined. Nutrient accumulation in herbaceous biomass was highest in 70% canopy pruning followed by 50% canopy pruning and control (unpruned). In pure crop (without tree) nutrient accumulation in herbaceous biomass was higher than that of the agrisilviculture system.
- The growth, yield and yield attributing characters of intercrops were significantly higher in 70% canopy pruning than 50% canopy pruning and control (unpruned). In pure crop (without tree), growth, yield and yield attributing characters of intercrops were comparatively higher than that of the agrisilviculture system.

- Soil microbial biomass C (C_{mic}), N (N_{mic}) and C_{mic}-to-N_{mic} ratio was higher before sowing of kharif crop as compared to after harvesting of rabi crop. Soil microbial biomass C and N was significantly higher in 70% canopy pruning than 50% canopy pruning and control (unpruned). However, soil C_{mic}-to-N_{mic} ratio was higher in control (unpruned) than 50 and 70% canopy pruning. In the agrisilviculture system, soil microbial biomass C and N was comparatively higher than pure crop (without tree) whereas soil C_{mic}-to-N_{mic} ratio was less than pure crop (without tree).
- The improvement in soil fertility was seen in *A. procera* based agrisilviculture system after two years of the study. There was slight increase in soil EC, OC, N, P, and K and decrease in pH in comparison to the state before experimentation.

Conclusions:

1. Growth, biomass, carbon and nutrient accumulation in *A. procera* was higher in unpruned trees as compared to 50 and 70% canopy pruned trees.
2. Biomass, carbon and nutrient accumulation in herbaceous layer was higher in 70% canopy pruning than 50% canopy pruning and control (unpruned).
3. Growth, yield and yield attributing characters of intercrops were higher in 70% canopy pruning than 50% canopy pruning and control (unpruned).
4. Soil microbial biomass C and N was higher in 70% canopy pruning than 50% canopy pruning and control, whereas soil C_{mic}-to-N_{mic} ratio was highest in control (unpruned) as compared to 50 and 70% canopy pruning.
5. There was slight decrease in soil pH and improvement in soil organic carbon, EC, available N, P and K in comparison to the state before experimentation.

The results of the present study therefore, pointed out the necessity of tree management (pruning) in agrisilviculture system. Pruning reduces the growth/biomass of tree component but increases the production of understorey vegetation besides improving timber quality of the trees. By adopting pruning practices in agrisilviculture systems, farmers could minimize the reduction in yield of understorey crop and meet an array of on farm needs of food, fodder, fuel wood and timber.

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7. LITERATURE CITED

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Appendix

APPENDIX

1. Meteorological data during the experimentation period

Month	Max. Temp. ^{O}C	Min Temp. ^{O}C	RH (%)	Rain fall (mm)	Rainy days	Evaporation (mm)
	2005 – 06					
June	41.7	26.9	48.9	14.2	2.0	12.0
July	32.6	25.2	79.4	214.6	14.0	5.4
August	33.7	24.2	73.2	82.8	4.0	5.4
September	33.3	24.0	77.7	75.5	7.0	4.4
October	34.1	15.5	56.1	1.8	0.0	5.4
November	30.1	10.1	53.4	0.0	0.0	3.5
December	24.0	5.2	63.8	1.2	0.0	2.3
January	24.1	6.2	65.2	0.0	0.0	2.8
February	31.6	11.7	62.9	0.0	0.0	4.2
March	31.8	14.1	63.8	24.2	2.0	5.1
April	40.0	19.8	43.8	0.8	0.0	9.0
May	41.8	25.6	48.3	52.2	4.0	10.5
	2006 – 07					
June	39.1	26.8	53.3	53.7	4.0	10.1
July	32.9	25.7	74.4	138.6	9.0	6.5
August	32.0	24.4	78.4	91.3	8.0	5.7
September	34.8	22.9	68.5	7.6	2.0	5.6
October	34.8	18.0	56.6	0.0	0.0	5.1
November	29.9	11.9	59.4	0.0	0.0	3.4
December	25.6	8.5	61.6	4.8	1.0	2.6
January	24.2	6.2	64.5	0.0	0.0	2.8
February	26.8	8.6	66.3	41	4.0	3.2
March	34.9	13.2	53.4	0.0	0.0	5.7
April	40.5	20.7	39.4	1.4	0.0	9.8
May	41.8	25.6	39.9	13.3	2.0	11.5

2. Analysis of Variance (ANOVA)

Source	Degree of Freedom	Sum of Squares	Mean Squares	F value	Prob
Replication	2				
Crop sequence	1				
Rep. × crop seq. (Error A)	2				
Pruning	2				
Crop seq. × pruning	2				
Rep. × crop seq. × pruning (Error B)	8				
Total	17				

3. Error Mean Sum of Square (EMSS) for tree growth and component wise biomass at different age

Source	Age	DBH	Height	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.000006	0.001539*	0.000106*	0.003572	0.000822	0.000653*	0.004486*
	5.5	0.033172	0.003489*	0.008656	0.069906	0.041587	0.067679	0.676979
	6.0	0.033406	0.003106*	0.001687*	0.001802*	0.129601	0.014363	0.236869
	6.5	0.026039	0.006217*	0.007000	0.028000*	0.126000	0.066000	0.725000
	7.0	0.063267	0.000739*	0.025859	0.232880	0.150921	0.219784	2.209298
Pruning	5.0	0.014664*	0.059897*	0.002939*	0.023047*	0.013378*	0.021054*	0.213053*
	5.5	0.037331*	0.032647*	0.007580*	0.051030*	0.052360*	0.057584*	0.599065*
	6.0	0.125406*	0.017247*	0.042963*	0.406369*	0.183743*	0.342994*	3.368772*
	6.5	0.059314*	0.074050*	0.019000*	0.149000*	0.132000*	0.154000*	1.570000*
	7.0	0.081469*	0.025236*	0.039618*	0.402672*	0.151017*	0.317980*	3.089401*
Crop seq. × pruning	5.0	0.014664	0.059897	0.002939	0.023047	0.013378	0.021054	0.213053
	5.5	0.037331	0.032647	0.007580	0.051030	0.052360	0.057584	0.599065
	6.0	0.125406	0.017247	0.042963	0.406369	0.183743	0.342994	3.368772
	6.5	0.059314	0.074050	0.019000	0.149000	0.132000	0.154000	1.570000
	7.0	0.081469	0.025236	0.039618	0.402672	0.151017	0.317980	3.089401

* Significant ($P \leq 0.05$)

4. EMSS for carbon content in tree components at different age

Source	Age (yrs)	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.000017*	0.001006	0.000150	0.000149*	0.001045*
	5.5	0.001745	0.016787	0.009402	0.014833	0.151633
	6.0	0.000340*	0.000441*	0.029349	0.003182	0.051383
	6.5	0.001000	0.007000*	0.028000	0.015000	0.162000
	7.0	0.005200	0.055734	0.034300	0.048000	0.498580
Pruning	5.0	0.000650*	0.005339*	0.003044*	0.004592*	0.047500*
	5.5	0.001529*	0.012244*	0.011848*	0.012581*	0.133460*
	6.0	0.008629*	0.097413*	0.041522*	0.075059*	0.757223*
	6.5	0.003000*	0.035000*	0.030000*	0.034000*	0.353000*
	7.0	0.007957*	0.096417	0.034096*	0.069572*	0.696904*
Crop seq. × pruning	5.0	0.000650	0.005339	0.003044	0.004592	0.047500
	5.5	0.001529	0.012244	0.011848	0.012581	0.133460
	6.0	0.008629	0.097413	0.041522	0.075059	0.757223
	6.5	0.003000	0.035000	0.030000	0.034000	0.353000
	7.0	0.007957	0.096417	0.034096	0.069572	0.696904

*Significant ($P \leq 0.05$)

5. EMSS for nutrient content in tree components at different age

5.1 Nitrogen

Source	Age (yrs)	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.085339*	0.440556	0.066172	0.105603*	1.065286*
	5.5	8.473979	8.152090	2.931855	10.756581*	115.5290
	6.0	1.661119*	0.210076*	9.143143	2.284862	29.15798
	6.5	5.955000	3.292000*	0.698000	10.414000	108.7140
	7.0	25.354442	27.13646	10.653262	34.850425	372.0430
Pruning	5.0	2.800703*	2.613831*	0.970889*	3.346896*	36.54622*
	5.5	7.424524*	5.958474*	3.694913*	9.134441*	100.0310*
	6.0	42.09800*	0.008445*	12.95822*	54.47615*	581.3890*
	6.5	18.10200*	17.38800*	9.301000*	24.22500*	261.4100*
	7.0	38.77515*	46.96075*	10.64780*	50.50997*	537.7720*
Crop seq. × pruning	5.0	2.800703	2.613831	0.970889	3.346896	36.54622
	5.5	7.424524	5.958474	3.694913	9.134441	100.0310
	6.0	42.097996	0.008445	12.958217	54.476146	581.3890
	6.5	18.102000	17.388000	9.301000	24.225000	261.4100
	7.0	38.775152	46.960747	10.647801	50.509968	537.7720

***Significant ($P \leq 0.05$)**

5.2 Phosphorus

Source	Age (yrs)	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.000322*	0.008073	0.000852	0.002773*	0.017568*
	5.5	0.033906	0.149277	0.038245	0.279124*	1.672054
	6.0	0.006704*	0.003880*	0.119651	0.059317	0.376333
	6.5	0.023869	0.060206*	0.113704	0.270090	1.570939
	7.0	0.101509	0.495686	0.139061	0.905060	5.440222
Pruning	5.0	0.011210*	0.047828*	0.012697*	0.086956*	0.524765*
	5.5	0.029686*	0.108958 *	0.048174*	0.237110*	1.429662*
	6.0	0.168619*	0.866475*	0.169198*	1.413722*	8.486800*
	6.5	0.072420*	0.318068*	0.121571*	0.628958*	3.790653*
	7.0	0.155357*	0.858447*	0.139069*	1.311256*	7.883518*
Crop seq. × pruning	5.0	0.011210	0.047828	0.012697	0.086956	0.524765
	5.5	0.029686	0.108958	0.048174	0.237110	1.429662
	6.0	0.168619	0.866475	0.169198	1.413722	8.486800
	6.5	0.072420	0.318068	0.121571	0.628958	3.790653
	7.0	0.155357	0.858447	0.139069	1.311256	7.883518

*Significant ($P \leq 0.05$)

5.3 Potassium

Source	Age (yrs)	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.003622*	0.044527	0.018428	0.015586*	0.070247 *
	5.5	0.363280	0.816854	0.826664	1.587814*	13.478749
	6.0	0.071182*	0.021163*	2.576684	0.336893	5.367400
	6.5	0.254902	0.329756*	2.453866	1.535709	15.052117
	7.0	1.086011	2.720294	3.003585	5.141846	44.067537
Pruning	5.0	0.120151*	0.261989*	0.273756*	0.493974*	4.235734*
	5.5	0.318299*	0.597170*	1.041633*	1.348000*	12.054460*
	6.0	1.804909*	4.754734*	3.652665*	8.038150*	66.590072*
	6.5	0.775706*	1.744098*	2.623748*	3.574749*	31.494028*
	7.0	1.662361*	4.709722*	3.002221*	7.453401*	60.869548*
Crop seq. × pruning	5.0	0.120151	0.261989	0.273756	0.493974	4.235734
	5.5	0.318299	0.597170	1.041633	1.348000	12.054460
	6.0	1.804909	4.754734	3.652665	8.038150	66.590072
	6.5	0.775706	1.744098	2.623748	3.574749	31.494028
	7.0	1.662361	4.709722	3.002221	7.453401	60.869548

***Significant ($P \leq 0.05$)**

5.4 Calcium

Source	Age (yrs)	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.028732*	0.085341	0.017069	0.217905*	0.641946*
	5.5	2.896376	1.569911	0.766910	22.19636*	72.897130
	6.0	0.567694*	0.040543*	2.393683	4.712724	18.359752
	6.5	2.033634	0.633353*	0.189023	0.151725	69.889217
	7.0	8.666643	5.227916	2.789053	71.912615	234.671000
Pruning	5.0	0.95822 *	0.502847*	0.254093*	6.905550*	22.953800*
	5.5	2.53809*	1.147775*	0.967722*	18.85093*	62.993776*
	6.0	14.39141*	9.133390*	3.392116*	112.4160*	366.32600*
	6.5	6.187396*	3.350313*	2.436938*	49.99100*	164.77700*
	7.0	13.25559*	9.046096*	2.787710*	104.2270*	338.46300*
Crop seq. × pruning	5.0	0.958218	0.502847	0.254093	6.905550	22.953800
	5.5	2.538088	1.147775	0.967722	18.850926	62.993776
	6.0	14.391409	9.133390	3.392116	112.41600	366.326000
	6.5	6.187396	3.350313	2.436938	49.990998	164.777000
	7.0	13.255586	9.046096	2.787710	104.22700	338.463000

*Significant ($P \leq 0.05$)

5.5. Magnesium accumulation in tree components at different age

Source	Age (yrs)	Foliage	Branch	Main bole	Root	Total biomass
Crop seq.	5.0	0.004486*	0.022190	0.000033	0.001312*	0.060819*
	5.5	0.453710	0.409668	0.001489	0.134680*	2.951857
	6.0	0.088932*	0.535344*	0.004605	0.028508	0.198066
	6.5	0.318154	0.165055 *	0.004447	0.130313	1.952517
	7.0	1.356176	1.362638	0.005459	0.436559	9.366862
Pruning	5.0	0.150131*	0.130968*	0.000500*	0.041844*	0.945072*
	5.5	0.397259*	0.299050*	0.001871*	0.114397*	2.406089*
	6.0	2.252623*	2.380619*	0.006605*	0.682244*	15.52034*
	6.5	0.968492*	0.873398*	0.004762*	0.303343*	6.378663*
	7.0	2.074204*	2.358369*	0.005464*	0.632160*	14.69772*
Crop seq. × pruning	5.0	0.150131	0.130968	0.000500	0.041844	0.945072
	5.5	0.397259	0.299050	0.001871	0.114397	2.406089
	6.0	2.252623	2.380619	0.006605	0.682244	15.52034
	6.5	0.968492	0.873398	0.004762	0.303343	6.378663
	7.0	2.074204	2.358369	0.005464	0.632160	14.69772

*Significant ($P \leq 0.05$)

6. EMSS for biomass, carbon and nutrients in litter fall of *Albizia procera*

Biomass/Carbon and nutrients	Source		
	Crop seq.	Pruning	Crop seq. × pruning
	2005 – 06		
Biomass	5.576992	19.291346*	19.291346
Carbon	1.044655	3.613573*	3.613573
N	0.001125	0.003890*	0.003890
P	0.000013	0.000045*	0.000045
K	0.000051	0.000176*	0.000176
Ca	0.001202	0.002156*	0.002156
Mg	0.000009	0.000017*	0.000017
	2006 – 07		
Biomass	48.261614*	59.183269*	59.183269
Carbon	9.040157*	11.085958*	11.085958
N	0.009732*	0.011934*	0.011934
P	0.000112*	0.000137*	0.000137
K	0.000440*	0.000540*	0.000540
Ca	0.003876*	0.008941*	0.008941
Mg	0.000031*	0.000071*	0.000071

*Significant ($P \leq 0.05$)

7. EMSS for biomass and carbon accumulation in fine roots of tree

Cropping period	Soil depth (cm)	Biomass			Carbon		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
Kharif, 2005	0–15	0.01012	6.91856	6.91856	0.00239	1.63346	1.63346
	15–30	0.01167	8.91374	8.91374	0.00275	2.10452	2.10452
	30–60	0.01883	7.82140	7.82140	0.00445	1.84663	1.84663
	Total	0.08306	25.76081	25.76081	0.01961	6.08210	6.08210
Kharif, 2006	0–15	0.04381	16.04641	16.04641	0.01034	3.78854	3.78854
	15–30	0.00642	10.11887	10.11887	0.00152	2.38905	2.38905
	30–60	0.04905	6.89962	6.89962	0.01158	1.62900	1.62900
	Total	0.25589	51.96364	51.96364	0.06042	12.26856	12.26856
Rabi, 2005 – 06	0–15	0.40408	7.84066	7.84066	0.09540	1.85117	1.85117
	15–30	0.01477	5.09365	5.09365	0.00349	1.20260	1.20260
	30–60	0.03540	9.20292	9.20292	0.00836	2.17280	2.17280
	Total	0.52426	17.14504	17.14504	0.12378	4.04792	4.04792
Rabi, 2006 – 07	0–15	0.00875	7.42344	7.42344	0.00207	1.75267	1.75267
	15–30	0.00947	5.87771	5.87771	0.00224	1.38772	1.38772
	30–60	0.03683	9.51250	9.51250	0.00869	2.24589	2.24589
	Total	0.07556	19.82445	19.82445	0.01784	4.68052	4.68052

* Significant ($P \leq 0.05$)

8. EMSS for biomass and carbon accumulation in small roots of tree

Cropping period	Soil depth (cm)	Biomass			Carbon		
		Crop seq.*	Pruning*	Crop seq. × pruning	Crop seq.*	Pruning*	Crop seq. × pruning
Kharif, 2005	0–15	0.06992	7.85326	7.85326	0.01616	1.81467	1.814673
	15–30	0.05648	4.25347	4.25347	0.01305	0.98286	0.982862
	30–60	0.04618	7.75387	7.75387	0.01067	1.79171	1.791708
	Total	0.05516	23.83579	23.83579	0.01275	5.50780	5.50780
Kharif, 2006	0–15	0.07377	19.79801	19.79801	0.01705	4.57478	4.57478
	15–30	0.00802	24.66650	24.66650	0.00185	5.69975	5.69975
	30–60	0.01469	26.42786	26.42786	0.00339	6.10675	6.10675
	Total	0.09765	159.98400	159.98400	0.02256	36.96800	36.96800
Rabi, 2005 – 06	0–15	0.00167	8.77613	8.77613	0.00039	2.02792	2.02792
	15–30	0.04216	5.78165	5.78165	0.00974	1.33598	1.33598
	30–60	0.01085	7.30532	7.30532	0.00251	1.68805	1.68805
	Total	0.10181	12.62759	12.62759	0.02352	2.91789	2.91789
Rabi, 2006 – 07	0–15	0.04227	23.41657	23.41657	0.00977	5.41093	5.41093
	15–30	0.01136	14.21814	14.21814	0.00262	3.28542	3.28542
	30–60	0.00391	14.15776	14.15776	0.00090	3.27147	3.27147
	Total	0.13217	72.80670	72.80670	0.03054	16.82363	16.82363

* Significant ($P \leq 0.05$)

9. EMSS for nutrient accumulation in fine root biomass

Source	Nutrients	Cropping period			
		Kharif		Rabi	
		2005	2006	2005 – 06	2006 – 07
Crop seq.*	N	0.000056	0.000172	0.000352	0.000051
	P	0.000001	0.000002	0.000002	0.000001
	K	0.000002	0.000007	0.000013	0.000002
	Ca	0.000029	0.000090	0.000185	0.000027
	Mg	0.0000002	0.000001	0.000001	0.0000002
Pruning*	N	0.017281	0.034858	0.011501	0.013298
	P	0.000229	0.000461	0.000152	0.000176
	K	0.000662	0.001336	0.000441	0.000510
	Ca	0.009105	0.018366	0.006059	0.007007
	Mg	0.000057	0.000115	0.000038	0.000044
Crop seq. × pruning *	N	0.017281	0.034858	0.011501	0.013298
	P	0.000229	0.000461	0.000152	0.000176
	K	0.000662	0.001336	0.000441	0.000510
	Ca	0.009105	0.018366	0.006059	0.007007
	Mg	0.000057	0.000115	0.000038	0.000044

* Significant ($P \leq 0.05$)

10. EMSS for nutrient accumulation in small root biomass

Source	Nutrients	Cropping period			
		Kharif		Rabi	
		2005	2006	2005 – 06	2006 – 07
Crop seq.*	N	0.000025	0.000045	0.000047	0.000061
	P	0.0000004	0.000001	0.000001	0.000001
	K	0.000001	0.000002	0.000002	0.000003
	Ca	0.000019	0.000033	0.000035	0.000045
	Mg	0.0000001	0.0000002	0.0000002	0.0000003
Pruning*	N	0.010916	0.073265	0.005783	0.033343
	P	0.000052	0.001192	0.000094	0.000543
	K	0.000570	0.003826	0.000302	0.001741
	Ca	0.008158	0.054755	0.004322	0.024918
	Mg	0.000045	0.000305	0.000024	0.000815
Crop seq. × pruning	N	0.010916	0.073265	0.005783	0.033343
	P	0.000052	0.001192	0.000094	0.000543
	K	0.000570	0.003826	0.000302	0.001741
	Ca	0.008158	0.054755	0.004322	0.024918
	Mg	0.000045	0.000305	0.000024	0.000815

* Significant ($P \leq 0.05$)

11. EMSS for biomass accumulation in herbaceous layer during kharif season

Component	Month	Kharif, 2005			Kharif, 2006		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
Crop	Aug.	0.146806	35.454861	35.454861	0.018100	47.195700	47.195700
	Sept.	0.487222	49.197014	49.197014	0.009600	58.120200	58.120200
	Oct.	0.300417	71.295486	71.295486	0.015800	37.853500	37.853500
Weed	Aug.	0.006822	38.302019	38.302019	0.008800	26.047300	26.047300
	Sept.	0.008225	27.839579	27.839579	0.000970	34.431300	34.431300
	Oct.	0.018822	34.693797	34.693797	0.004660	33.951000	33.951000
Floor litter	Aug.	-	-	-	-	-	-
	Sept.	0.008089	0.839756	0.839756	0.011312	3.369653	3.369653
	Oct.	0.477016	1.289905	1.289905	0.006670	6.964800	6.964800
Root	Aug.	0.004709	7.429364	7.429364	0.010100	0.685400	0.685400
	Sept.	0.028714	0.792784	0.792784	0.013900	0.676600	0.676600
	Oct.	0.006689	5.506989	5.506989	0.000476	0.559400	0.559400
Grains		0.001585	24.422974	24.422974**	12.082756	7.936756	7.936756**

* Significant ($P \leq 0.05$)
** Non significant ($P \geq 0.05$)

12. EMSS for carbon accumulation in herbaceous biomass during kharif season

Component	Month	Kharif, 2005			Kharif, 2006		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
Crop	Aug.	0.026248	6.222827	6.222827	0.002867	8.346100	8.346100
	Sept.	0.089951	8.822900	8.822900	0.001672	10.560800	10.560800
	Oct.	0.054866	12.800462	12.800462	0.002822	6.819500	6.819500
Weed	Aug.	0.001138	6.556844	6.556844	0.001439	4.640100	4.640100
	Sept.	0.001487	4.980435	4.980435	0.000200	6.448500	6.448500
	Oct.	0.003570	6.251610	6.251610	0.000689	6.111689	6.111689
Floor litter	Aug.	-	-	-	-	-	-
	Sept.	0.001430	0.151663	0.151663	0.002015	0.587697	0.587697
	Oct.	0.076547	0.216885	0.216885	0.001072	1.121939	1.121939
Root	Aug.	0.000843	1.352082	1.352082	0.002072	0.124156	0.124156
	Sept.	0.005314	0.146671	0.146671	0.002317	0.124686	0.124686
	Oct.	0.001248	1.031536	1.031536	0.000117	0.104444	0.104444
Grains		0.000306	4.739482	4.739482**	2.341771	1.540940	1.540940**

* Significant ($P \leq 0.05$)
** Non significant ($P \geq 0.05$)

13. EMSS for nutrient accumulation in aboveground biomass of herbaceous layer during kharif season.

Nutrient	Month/ Grain	Kharif, 2005			Kharif, 2006		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
N	Aug.	0.000061	0.018429	0.018429	0.000005	0.013713	0.013713
	Sept.	0.000222	0.018349	0.018349	0.000002	0.025194	0.025194
	Oct.	0.000036	0.031763	0.000036	0.000012	0.024402	0.024402
	Grain	0.000002	0.023305	0.023305**	0.011634	0.007547	0.007547**
P	Aug.	0.000001	0.000332	0.000332	0.0000001	0.000237	0.000237
	Sept.	0.000004	0.000263	0.000263	0.00000003	0.000415	0.000415
	Oct.	0.000001	0.000280	0.000280	0.0000002	0.000445	0.000445
	Grain	0.000000	0.000510	0.000510**	0.000254	0.000165	0.000165**
K	Aug.	0.000022	0.013298	0.013298	0.000003	0.006931	0.006931
	Sept.	0.000057	0.006243	0.006243	0.000001	0.010220	0.010220
	Oct.	0.000012	0.009403	0.009403	0.000002	0.007356	0.007356
	Grain	0.000000	0.001465	0.001465**	0.000803	0.000453	0.000453**
Ca	Aug.	0.000003	0.001915	0.001915	0.000001	0.001075	0.001075
	Sept.	0.000013	0.001946	0.001946	0.0000004	0.002216	0.002216
	Oct.	0.000029	0.003399	0.003399	0.0000003	0.001662	0.001662
	Grain	0.000001	0.005257	0.005257**	0.002914	0.001617	0.001617**
Mg	Aug.	0.0000004	0.000176	0.000176	0.00000005	0.000108	0.000108
	Sept.	0.000002	0.000157	0.000157	0.00000002	0.000211	0.000211
	Oct.	0.0000003	0.000282	0.000282	0.0000001	0.000217	0.000217
	Grain	0.000000004	0.000053	0.000053**	0.000027	0.000017	0.000017**

* Significant ($P \leq 0.05$)
** Non significant ($P \geq 0.05$)

14. EMSS for nutrient accumulation in belowground biomass of herbaceous layer during kharif season.

Nutrient	Month	Kharif, 2005			Kharif, 2006		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
N	Aug.	0.000001	0.001820	0.001820	0.000002	0.000179	0.000179
	Sept.	0.000007	0.000199	0.000199	0.000003	0.000166	0.000166
	Oct.	0.000001	0.001260	0.001260	0.0000001	0.000118	0.000118
P	Aug.	0.00000001	0.000055	0.000055	0.0000001	0.000003	0.000003
	Sept.	0.0000001	0.000003	0.000003	0.0000001	0.000003	0.000003
	Oct.	0.00000003	0.000033	0.000033	0.000000004	0.000002	0.000002
K	Aug.	0.0000004	0.000345	0.000345	0.0000004	0.000050	0.000050
	Sept.	0.000002	0.000048	0.000048	0.000001	0.000036	0.000036
	Oct.	0.0000003	0.000155	0.000155	0.0000001	0.000024	0.000024
Ca	Aug.	0.0000001	0.000244	0.000244	0.0000004	0.000015	0.000015
	Sept.	0.000001	0.000019	0.000019	0.0000003	0.000018	0.000018
	Oct.	0.0000002	0.000175	0.000175	0.000000009	0.000014	0.000014
Mg	Aug.	0.00000001	0.000016	0.000016	0.00000002	0.000001	0.000001
	Sept.	0.000051	0.000061	0.000061	0.000065	0.000073	0.000073
	Oct.	0.00000001	0.000011	0.000011	0.000000001	0.000001	0.000001

* Significant ($P \leq 0.05$)

15. EMSS for biomass accumulation in herbaceous during rabi season.

Component	Month	Rabi, 2005 – 06			Rabi, 2006 – 07		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
Crop seq.	Dec.	0.00896	1412.520	1412.520	0.01860	952.02100	952.02100
	Jan.	0.00011	5029.470	5029.470	0.00549	537.82100	537.82100
	Feb.	0.00512	6342.710	6342.710	0.06487	1533.430	1533.430
	Mar.	0.00401	7873.380	7873.380	0.03792	5173.590	5173.590
Weed	Dec.	0.01354	617.73200	617.73200	0.11927	119.44600	119.44600
	Jan.	0.09704	928.31600	928.31600	0.02535	429.67400	429.67400
	Feb.	0.00247	1093.630	1093.630	0.10827	371.94100	371.94100
	Mar.	0.00315	649.30800	649.30800	0.00957	217.21900	217.21900
Floor litter	Dec.	-	-	-	-	-	-
	Jan.	-	-	-	-	-	-
	Feb.	-	-	-	-	-	-
	Mar.	0.00011	454.31800	454.31800	0.00572	72.72000	72.72000
Root	Dec.	0.00667	46.67170	46.67170	0.01828	12.05210	12.05210
	Jan.	0.00549	203.11400	203.11400	0.01331	6.76563	6.76563
	Feb.	0.00421	385.64300	385.64300	0.00580	24.22790	24.22790
	Mar.	0.00952	546.20300	546.20300	0.00764	78.89240	78.89240
Grains		40.35220	222.33800	222.33800**	165.46900	3404.060	3404.060**

* Significant ($P \leq 0.05$)
** Non significant ($P \geq 0.05$)

16. EMSS for carbon accumulation in herbaceous biomass during rabi season

Component	Month	Rabi, 2005 – 06			Rabi, 2006 – 07		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
Crop seq.	Dec.	0.00185	257.25000	257.25000	0.00339	173.81200	173.81200
	Jan.	0.00002	1015.130	1015.130	0.00112	108.37900	108.37900
	Feb.	0.00107	1272.660	1272.660	0.01300	307.17300	307.17300
	Mar.	0.00091	1538.230	1538.230	0.00741	1012.370	1012.370
Weed	Dec.	0.00236	106.44900	106.44900	0.02025	20.22810	20.22810
	Jan.	0.01725	166.83400	166.83400	0.00455	76.83340	76.83340
	Feb.	0.00045	194.05600	194.05600	0.01915	65.50210	65.50210
	Mar.	0.00057	113.99500	113.99500	0.00171	37.86370	37.86370
Floor litter	Dec.	-	-	-	-	-	-
	Jan.	-	-	-	-	-	-
	Feb.	-	-	-	-	-	-
	Mar.	0.00002	72.74180	72.74180	0.00090	12.16670	12.16670
Root	Dec.	0.00124	8.69374	8.69374	0.00342	2.24552	2.24552
	Jan.	0.00110	41.22550	41.22550	0.00268	1.36871	1.36871
	Feb.	0.00087	80.04340	80.04340	0.00120	4.99986	4.99986
	Mar.	0.00195	113.42900	113.42900	0.00159	16.26150	16.26150
Grains		7.50486	47.14040	47.14040**	32.27290	653.54200	653.54200**

* Significant ($P \leq 0.05$)
** Non significant ($P \geq 0.05$)

17. EMSS for nutrient accumulation in aboveground biomass of herbaceous layer during rabi season.

Nutrient	Month/ Grain	Rabi, 2005 – 06			Rabi, 2006 – 07		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
N	Dec.	0.000003	0.466345	0.466345	0.000064	0.347999	0.347999
	Jan.	0.000031	2.341380	2.341380	0.000007	0.217438	0.217438
	Feb.	0.000001	1.725356	1.725356	0.000043	0.475237	0.475237
	Mar.	0.000002	1.805066	1.805066	0.000014	1.371777	1.371777
	Grain	0.014050	0.113226	0.113226	0.065850	1.310860	1.310860
P	Dec.	0.0000001	0.008924	0. 008924	0.000001	0.005343	0.005343
	Jan.	0.0000004	0.039052	0.039052	0.0000001	0.003431	0.003431
	Feb.	0.00000003	0.047157	0.047157	0.000001	0.011452	0.011452
	Mar.	0.00000005	0.047704	0.047704	0.0000005	0.040626	0.040626
	Grain	0.000625	0.004381	0.004381	0.002792	0.000165	0.000165
K	Dec.	0.000003	0.485586	0.485586	0.000083	0.392861	0.392861
	Jan.	0.000030	3.179912	3.179912	0.000014	0.238089	0.238089
	Feb.	0.000003	2.662478	2.662478	0.000066	0.586422	0.586422
	Mar.	0.000006	1.333441	1.333441	0.000016	1.263213	1.263213
	Grain	0.002364	0.023086	0.023086	0.011845	0.234650	0.234650
Ca	Dec.	0.0000004	0.038634	0.038634	0.000006	0.015059	0.015059
	Jan.	0.000004	0.063515	0.063515	0.0000001	0.015170	0.015170
	Feb.	0.00000001	0.150100	0.150100	0.000003	0.043902	0.043902
	Mar.	0.00000004	0.248009	0.248009	0.000004	0.198237	0.198237
	Grain	0.004607	0.032327	0.032327	0.020589	0.413068	0.413068
Mg	Dec.	0.000001	0.021421	0.021421	0.000002	0.005154	0.005154
	Jan.	0.000001	0.021421	0.021421	0.00000003	0.005219	0.005219
	Feb.	0.00000001	0.038498	0.038498	0.000001	0.016074	0.016074
	Mar.	0.00000001	0.083918	0.00000001	0.000001	0.066561	0.066561
	Grain	0.000017	0.000485	0.000485	0.000130	0.002768	0.002768

* Significant ($P \leq 0.05$)

18. EMSS for nutrient accumulation in belowground biomass of herbaceous layer during rabi season.

Nutrient	Month	Rabi, 2005 – 06			Rabi, 2006 – 07		
		Crop seq.*	Pruning*	Crop seq. × pruning*	Crop seq.*	Pruning*	Crop seq. × pruning*
N	Dec.	0.000002	0.014043	0.014043	0.000006	0.003633	0.003633
	Jan.	0.000001	0.059068	0.059068	0.000004	0.001913	0.001913
	Feb.	0.000001	0.103253	0.103253	0.000002	0.006197	0.006197
	Mar.	0.000002	0.071970	0.071970	0.000001	0.015645	0.015645
P	Dec.	0.00000002	0.000087	0.000087	0.00000005	0.000036	0.000036
	Jan.	0.00000002	0.000496	0.000496	0.00000005	0.000019	0.000019
	Feb.	0.00000001	0.000877	0.000877	0.00000001	0.000064	0.000064
	Mar.	0.00000003	0.001162	0.001162	0.00000002	0.000228	0.000228
K	Dec.	0.000001	0.005930	0.005930	0.000001	0.001487	0.001487
	Jan.	0.000002	0.022736	0.022736	0.000003	0.001080	0.001080
	Feb.	0.0000005	0.035026	0.035026	0.0000005	0.003286	0.003286
	Mar.	0.000002	0.042009	0.042009	0.000001	0.013808	0.013808
Ca	Dec.	0.0000001	0.000565	0.000565	0.0000001	0.000139	0.000139
	Jan.	0.0000002	0.002194	0.002194	0.0000004	0.000123	0.000123
	Feb.	0.0000001	0.003641	0.003641	0.00000004	0.000406	0.000406
	Mar.	0.0000004	0.004036	0.004036	0.0000003	0.001881	0.001881
Mg	Dec.	0.00000004	0.000193	0.000193	0.00000002	0.000048	0.000048
	Jan.	0.0000001	0.000747	0.000747	0.0000001	0.000042	0.000042
	Feb.	0.00000002	0.001209	0.001209	0.00000001	0.000136	0.000136
	Mar.	0.0000001	0.001301	0.001301	0.0000001	0.000623	0.000623

* Significant ($P \leq 0.05$)

19. N. P, K, Ca and Mg concentration (% ± SE, n = 10) in biomass of tree component and herbaceous layer

(a) Tree component

Component	C	N	P	K	Ca	Mg
Main bole	47.57 ± 0.036	0.84 ± 0.018	0.096 ± 0.013	0.446 ± 0.003	0.430 ± 0.005	0.019 ± 0.002
Branch	48.93 ± 0.032	1.08 ± 0.021	0.146 ± 0.022	0.342 ± 0.005	0.474 ± 0.003	0.242 ± 0.006
Leaf	44.84 ± 0.026	3.13 ± 0.012	0.198 ± 0.010	0.648 ± 0.004	1.830 ± 0.011	0.742 ± 0.003
Litter fall	43.28 ± 0.017	1.42 ± 0.025	0.152 ± 0.006	0.302 ± 0.001	1.800 ± 0.010	0.160 ± 0.017
Coarse root	46.78 ± 0.025	1.26 ± 0.031	0.203 ± 0.007	0.484 ± 0.004	1.810 ± 0.012	0.141 ± 0.008
Fine root	48.59 ± 0.021	2.59 ± 0.039	0.298 ± 0.009	0.507 ± 0.001	1.880 ± 0.015	0.149 ± 0.012

(b) Herbaceous layer

I-Greengram

Crop	C	N	P	K	Ca	Mg
30 DAS	41.81 ± 0.043	1.79 ± 0.011	0.190 ± 0.004	1.124 ± 0.003	0.592 ± 0.001	0.157 ± 0.004
60 DAS	42.12 ± 0.038	1.76 ± 0.039	0.188 ± 0.008	0.941 ± 0.005	0.589 ± 0.003	0.156 ± 0.002
90 DAS	41.85 ± 0.029	1.62 ± 0.011	0.182 ± 0.007	0.802 ± 0.003	0.580 ± 0.001	0.145 ± 0.004
Weed						
30 DAS	43.40 ± 0.040	1.40 ± 0.005	0.171 ± 0.004	1.550 ± 0.004	0.599 ± 0.006	0.164 ± 0.002
60 DAS	43.62 ± 0.027	1.44 ± 0.006	0.162 ± 0.002	1.462 ± 0.003	0.597 ± 0.003	0.162 ± 0.001
90 DAS	43.50 ± 0.038	1.43 ± 0.019	0.166 ± 0.006	0.981 ± 0.003	0.588 ± 0.007	0.156 ± 0.003
Floor litter						
60 DAS	41.68 ± 0.027	1.48 ± 0.004	0.180 ± 0.003	0.902 ± 0.004	0.585 ± 0.004	0.147 ± 0.005
90 DAS	40.05 ± 0.041	1.46 ± 0.005	0.177 ± 0.004	0.782 ± 0.003	0.576 ± 0.006	0.139 ± 0.003
Root						
30 DAS	42.68 ± 0.035	1.56 ± 0.024	0.278 ±0.003	0.662 ± 0.005	0.582 ± 0.006	0.149 ± 0.005
60 DAS	43.05 ± 0.040	1.54 ± 0.035	0.264 ± 0.006	0.618 ± 0.001	0.579 ± 0.007	0.148 ± 0.004
90 DAS	43.29 ± 0.019	1.52 ± 0.019	0.251 ± 0.004	0.512 ± 0.003	0.571 ± 0.003	0.141 ± 0.001
Grains	44.07 ± 0.023	3.08 ± 0.027	0.456 ± 0.002	0.743 ± 0.002	1.400 ± 0.007	0.145 ± 0.002

II. Blackgram

Crop	C	N	P	K	Ca	Mg
30 DAS	42.25 ± 0.025	1.86 ± 0.024	0.251 ± 0.003	1.024 ±0.006	0.429 ± 0.004	0.152 ± 0.005
60 DAS	42.96 ± 0.034	1.84 ± 0.029	0.246 ± 0.007	0.881 ± 0.009	0.427 ± 0.007	0.150 ± 0.002
90 DAS	42.88 ± 0.019	1.68 ± 0.031	0.233 ± 0.004	0.728 ± 0.004	0.404 ± 0.003	0.144 ± 0.001
Weed						
30 DAS	40.68 ± 0.025	1.43 ±0.025	0.241 ± 0.005	1.591 ± 0.004	0.447 ± 0.001	0.159 ± 0.007
60 DAS	42.27 ± 0.015	1.49 ± 0.034	0.237 ± 0.003	1.017 ± 0.003	0.446 ± 0.003	0.158 ± 0.005
90 DAS	41.18 ± 0.015	1.47 ± 0.032	0.227 ± 0.004	0.991 ± 0.005	0.438 ± 0.004	0.147 ± 0.002
Floor litter						
60 DAS	42.73 ± 0.020	1.72 ± 0.037	0.207 ± 0.003	0.856 ± 0.005	0.413 ± 0.003	0.147 ± 0.001
90 DAS	41.34 ± 0.025	1.67 ± 0.031	0.201 ± 0.005	0.702 ± 0.004	0.401 ± 0.005	0.141 ± 0.003
Root						
30 DAS	42.33 ± 0.031	1.65 ± 0.014	0.139 ± 0.003	0.952 ± 0.003	0.397 ± 0.005	0.145 ± 0.002
60 DAS	42.98 ± 0.025	1.62 ± 0.032	0.120 ± 0.004	0.889 ± 0.004	0.395 ± 0.007	0.143 ± 0.005
90 DAS	43.08 ± 0.043	1.36 ± 0.027	0.118 ± 0.002	0.802 ± 0.002	0.388 ± 0.003	0.138 ± 0.001
Grains	43.93 ± 0.019	3.15 ± 0.034	0.463 ± 0.005	0.961 ± 0.009	1.860 ± 0.034	0.158 ± 0.003

III. Mustard

Crop	C	N	P	K	Ca	Mg
30 DAS	42.64 ± 0.027	1.84 ± 0.042	0.265 ± 0.006	1.721 ± 0.003	0.578 ± 0.006	0.336 ± 0.001
60 DAS	44.77 ± 0.029	1.82 ± 0.023	0.259 ± 0.004	1.672 ± 0.002	0.577 ± 0.003	0.335 ± 0.004
90 DAS	44.68 ± 0.045	1.59 ± 0.027	0.250 ± 0.006	1.209 ± 0.004	0.562 ± 0.008	0.327 ± 0.002
At harvest	44.12 ± 0.035	1.44 ± 0.039	0.243 ± 0.002	1.081 ± 0.005	0.560 ± 0.002	0.325 ± 0.005
Weed						
30 DAS	41.06 ± 0.034	1.70 ±0.034	0.217 ±0.004	1.927 ± 0.009	0.589 ± 0.002	0.349 ± 0.007
60 DAS	42.18 ± 0.017	1.72 ± 0.023	0.203 ± 0.003	1.742 ± 0.004	0.587 ± 0.004	0.347 ± 0.005
90 DAS	41.82 ± 0.021	1.37 ± 0.016	0.198 ± 0.002	1.238 ± 0.006	0.574 ± 0.001	0.335 ± 0.002
At harvest	41.67 ± 0.043	1.31 ± 0.040	0.194 ± 0.004	1.098 ± 0.007	0.572 ± 0.005	0.333 ± 0.006

Continue

Floor litter						
90 DAS	39.40 ± 0.035	1.06 ± 0.039	0.237 ± 0.006	1.072 ± 0.002	0.558 ± 0.003	0.319 ± 0.005
At harvest	40.01 ± 0.029	0.98 ± 0.030	0.224 ± 0.003	1.043 ± 0.003	0.553 ± 0.001	0.315 ± 0.004
Root						
30 DAS	42.99 ±0.041	1.68 ± 0.041	0.193 ± 0.004	1.582 ± 0.006	0.559 ± 0.002	0.327 ± 0.004
60 DAS	44.85 ± 0.024	1.64 ± 0.034	0.188 ± 0.006	1.556 ± 0.003	0.557 ± 0.003	0.326 ± 0.006
90 DAS	45.19 ± 0.017	1.53 ± 0.026	0.182 ± 0.002	1.472 ± 0.004	0.548 ± 0.001	0.317 ± 0.003
At harvest	45.34 ± 0.022	1.49 ± 0.023	0.178 ± 0.007	1.449 ± 0.008	0.545 ± 0001	0.314 ± 0.005
Grains	53.47 ± 0.027	3.11 ± 0.019	0.563 ± 0.003	1.525 ± 0.002	1.530 ± 0.002	0.269 ± 0.001

IV. Wheat

Crop	C	N	P	K	Ca	Mg
30 DAS	42.74 ± 0.030	1.77 ± 0.026	0.212 ± 0.003	1.957 ± 0.003	0.194 ± 0.003	0.112 ± 0.004
60 DAS	44.95 ± 0.040	1.73 ± 0.037	0.209 ± 0.006	1.948 ± 0.002	0.192 ± 0.001	0.110 ± 0.003
90 DAS	44.83 ± 0.027	1.27 ± 0.022	0.206 ± 0.004	1.874 ± 0.005	0.187 ± 0.004	0.106 ± 0.001
120 DAS	44.54 ± 0.019	1.04 ± 0.029	0.202 ± 0.002	1.759 ± 0.003	0.182 ± 0.003	0.102 ± 0.004
At harvest	44.27 ± 0.024	1.02 ± 0.019	0.199 ± 0.003	1.734 ± 0.002	0.181 ± 0.002	0.101 ± 0.002
Weed						
30 DAS	41.67 ± 0.017	1.26 ±0.023	0.207 ± 0.005	1.992 ± 0.006	0.206 ± 0.003	0.121 ± 0.001
60 DAS	42.51 ± 0.034	1.25 ± 0.026	0.203 ± 0.002	1.921 ± 0.004	0.204 ± 0.005	0.120 ± 0.003
90 DAS	42.35 ± 0.039	1.13 ± 0.029	0.196 ± 0.003	1.827 ± 0.004	0.198 ± 0.003	0.117 ± 0.001
120 DAS	42.30 ± 0.026	1.12 ± 0.025	0.193 ± 0.001	1.821 ± 0.003	0.193 ± 0.006	0.113 ± 0.002
At harvest	42.05 ± 0.031	1.08 ± 0.019	0.180 ± 0.003	1.819 ± 0.002	0.191 ± 0.004	0.111 ± 0.005
Floor litter						
120 DAS	42.04 ± 0.025	0.98 ± 0.026	0.198 ± 0.004	1.886 ±0.003	0.177 ± 0.005	0.099 ± 0.001
At harvest	40.76 ± 0.016	0.90 ± 0.032	0.192 ± 0.003	1.856 ± 0.006	0.174 ± 0.003	0.097 ± 0.002

Continue

Root						
30 DAS	43.24 ± 0.024	1.76 ± 0.025	0.164 ± 0.003	0.827 ± 0.005	0.173 ± 0.005	0.101 ± 0.001
60 DAS	45.13 ± 0.036	1.73 ± 0.037	0.142 ± 0.005	0.784 ± 0.004	0.172 ± 0.003	0.099 ± 0.001
90 DAS	45.68 ± 0.022	1.67 ± 0.028	0.139 ± 0.003	0.701 ± 0.003	0.162 ± 0.001	0.092 ± 0.003
120 DAS	45.62 ± 0.027	1.06 ± 0.019	0.138 ± 0.002	0.695 ± 0.006	0.161 ± 0.004	0.088 ± 0.005
At harvest	45.99 ± 0.016	1.04 ± 0.015	0.134 ± 0.004	0.512 ± 0.004	0.160 ± 0.002	0.087 ± 0.002
Grains	43.16 ± 0.034	1.87 ± 0.022	0.394 ± 0.003	0.768 ± 0.002	1.070 ± 0.003	0.065 ± 0.005

20. EMSS for microbial biomass carbon (MBC), nitrogen (MBN) and MBC: MBN ratio

Source	2005 – 06		2006 – 07		2005 – 06		2006 – 07		2005 – 06		2006 – 07	
	MBC Kharif	MBC rabi	MBC kharif	MBC rabi	MBN Kharif	MBN rabi	MBN kharif	MBN rabi	MBC: MBN kharif	MBC: MBN rabi	MBC: MBN kharif	MBC: MBN rabi
Crop seq.	2.12272	1.65912	22.05927	0.76301	23.9589	0.13217	0.48292	0.10792	0.1567	0.0016	0.0006	0.0018
Pruning	19.81752*	16.35742*	23.53354*	7.30631*	2.8442*	2.08619*	1.34727*	0.7598*	0.0149	0.0213	0.0122	0.0036
Crop seq. × pruning	19.81752	16.35742	23.53354	7.30631	2.8442	2.08619	1.34727	0.7598	0.0149	0.0213	0.0122	0.0036

* Significant ($P \leq 0.05$)

21. EMSS for physico-chemical properties of soil

Source	Initial						End of the study					
	pH	EC	OC	N	P	K	pH	EC	OC	N	P	K
	0 – 15 cm soil depth											
Crop seq.	0.000022	0.000034	0.005506	35.17805	12.10465	5.648600	0.005106	0.000026	0.008289	28.34082	19.52737	46.6067
Pruning*	0.000006	0.0000001	0.000253	0.774775	0.082003	0.178567	0.000006	0.0000001	0.000297	1.463361	0.165444	2.741536
Crop seq. × pruning	0.000006	0.0000001	0.000253	0.774775	0.082003	0.178567	0.000006	0.0000001	0.000297	1.463361	0.165444	2.741536
	15 – 30 cm soil depth											
Crop seq.	0.000072	0.000001	0.005717	55.32809	3.482917	43.49345	0.014506	0.0000002	0.012150	61.08107	23.30375	6.095872
Pruning*	0.000061	0.0000004	0.000058	1.580681	0.237619	0.171294	0.000028	0.0000001	0.000036	0.416531	0.052758	0.484519
Crop seq. × pruning	0.000061	0.0000004	0.000058	1.580681	0.237619	0.171294	0.000028	0.0000001	0.000036	0.416531	0.052758	0.484519

* Significant ($P \leq 0.05$)